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INTERACTIONAL AERODYNAMICS OF THE SINGLE ROTOR HELICOPTER CONFI--ETC(U)
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USARTL-TR-78-23G

INTERACTIONAL AERODYNAMICS OF THE SINGLE ROTOR HELICOPTER CONFIGURATION

OLUME VII-D - Frequency Analyses of Wake Split-Film Data, Open Hubcaps

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Prepared for

APPLIED TECHNOLOGY LABORATORY

U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

In 1975 a wind tunnel test program was conducted in the Boeing-Vertol 20-foot V/STOL. Wind Tunnel on a 1/5th-scale UTTAS model to investigate and find solutions for several aerodynamic problems encountered during the UTTAS flight-testing. Specifically, these tests focused upon (a) the structure of the hub/rotor wake in the vicinity of the empennage, (b) the formulation of the ground vortex and its relation to hub loads and fuselage loads during transition, and (c) the occurrence of vibratory air pressures from the blade passing over the fuselage. Only portions of the above-mentioned wind tunnel test data were reduced and analyzed in addressing the flight-test problems of the UTTAS aircraft.

Under Contract DAAJ02-77-C-0020, Boeing-Vertol completed analyses on the data to understand more completely the aerodynamic interactions that are involved and to formulate instructions for the guidance of designers in these respects. The results of these studies are applicable to all existing and future single-rotor/tail rotor helicopters. The data have been segregated according to aerodynamic interactions and associated phenomena/problem areas. From this body of knowledge, a generalized set of design guidelines meaningful to the single-rotor helicopter design concept formulation were developed and are included in these reports.

Mr. Robert P. Smith of the Aeronautical Technology Division, Aeromechanics Technical Area, served as project engineer for this effort.

DISCLAIMERS

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) READ INSTRUCTIONS REPORT DOCUMENTATION PAGE BEFORE COMPLETING FORM 2. GOVT ACCESSION NO. 3. RECIPIENT'S CATALOG NUMBER TR-78-23G USARTL-SINGLE ROTOR HELICOPTER CONFIGURATION. MOD COVERED Volume Frequency Analyses of Wake Split-Film Data, Open Hubcaps. 15 Mar 277 - 13 Feb 378 AUTHOR(e) CONTRACT OR GRANT NUMBER(a) Philip F./ Sheridan DAAJ92-77-C-9020 PERFORMING ORGANIZATION NAME AND ADDRESS PROGRAM ELEMENT, PROJECT, TASK AREA, A, WORK UNIT NUMBERS Boeing Vertol Company P.O. Box 16858 622-0A 1L262209AH76 Philadelphia, Pa. 19142 00 189 FK 11. CONTROLLING OFFICE NAME AND ADDRESS Septe Applied Technology Laboratory, US Army Researth/ and Technology Laboratories (AVRADCOM) FORT EUSTIS, VIRGINIA 23604

14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office) 399 SECURITY CLASS. (of this report) Unclassified DECLASSIFICATION/DOWNGRADING 16. DISTRIBUTION STATEMENT (of this Report) A062 Approved for public release; distribution unlimited. 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) 18. SUPPLEMENTARY NOTES Volume VII of an eight-volume report Volume VII is comprised of seven sub-volumes (A thru G) 19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Wake Empennage Flow Aerodynamic Interaction Flow Modifier Frequency Flow Environment Powered Model Spectrum Configuration Hub Cap This is the fourth of seven sub-volumes of Volume VII containing spectrographs of the model helicopter hub/rotor wake as it was modified by various aerodynamic devices. This sub-volume deals with the effects of various open hub caps. Open caps have parallel undersides and uppersides.

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PREFACE

The entire report describing the investigation of INTERACTIONAL AERODYNAMICS OF THE SINGLE-ROTOR HELICOPTER CONFIGURATION comprises eight numbered volumes bound as 33 separate documents. The complete list of these documents is as follows:

Volume I, Final Report

Volume II, Harmonic Analyses of Airframe Surface Pressure Data

- A Runs 7-14, Forward Section
- B Runs 7-14, Mid Section
- C Runs 7-14, Aft Section
- D Runs 15-22, Forward Section
- E Runs 15-22, Mid Section
- F Runs 15-22, Aft Section
- G Runs 23-33, Forward Section
- H Runs 23-33, Mid Section
- I Runs 23-33, Aft Section

Volume III, Flow Angle and Velocity Wake Profiles in Low-Frequency Band

- A Basic Investigations and Hubcap Variations
- B Air Ejector Systems and Other Devices

Volume IV, One-Third Octave Band Spectrograms of Wake Split-Film Data

- A Buildup to Baseline
- B Basic Configuration Wake Explorations
- C Solid Hubcaps
- D Open Hubcaps
- E Air Ejectors
- F Air Ejectors With Hubcaps; Wings
- G Fairings and Surface Devices

Volume V, Harmonic Analyses of Hub Wake

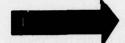
Volume VI, One-Third Octave Band Spectrograms of Wake Single Film Data

- A Buildup to Baseline
- B Basic Configuration Wake Exploration
- C Hubcaps and Air Ejectors

Volume VII, Frequency Analyses of Wake Split-Film Data

- A Buildup to Baseline
- B Basic Configuration Wake Explorations
- C Solid Hubcaps

Film Data Justice Trations Processing Proces



D - Open Hubcaps

E - Air Ejectors

F - Air Ejectors With Hubcaps; Wings

G - Fairings and Surface Devices

Volume VIII, Frequency Analyses of Wake Single Film Data

A - Buildup to Baseline

B - Basic Configuration Wake Exploration

C - Hubcaps and Air Ejectors

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INTRODUCTION

Volume VII presents an array of machine plotted graphs of wake angle and velocity versus frequency in the band from 4 to 240 Hz derived from the split film transducers. This encompasses data in the spectrum through 10 times rotor speed which is 1433 RPM or 23.88 Hz.

The graphs showing wake frequency spectra are sequenced in the same order as the Outline of Wake Investigations (Table I). These graphs are distributed among Volumes VII-A through VII-G by the major categories of Table I in the following arrangement:

Volume VII-A - Build-up to Baseline
Volume VII-B - Basic Configuration
Volume VII-C - Effect of Mub Caps Sec

Volume VII-C - Effect of Hub Caps Sections 1 & 2
Volume VII-D - Effect of Hub Caps Sections 3 & 4
Volume VII-E - Effect of Hub Caps Section 5 and
Effect of Air Ejectors

Volume VII-F - Air Ejectors with Open Hub Caps and Effect of Wings and Misc. Section 1

Volume VII-G - Effect of Wings and Misc. Sections 2 & 3

The Table I outline and other material is included for reference and as context to the work of each sub-volume. Table 2, the List of Test Runs, arranges the runs in numerical order and gives pertinent text parameters.

The Index of Rake Positions, Table 3, lists the hot film transducer rake positions in the model coordinate system for each run and its test points. The main feature of Table 3 is the indexing of the test point number to the model water line station and butt line as it varied from run to run. The table groups the runs as they shared the indexing correspondence of point with position. It is emphasized that the runs in a group do not necessarily all share the same number of test points but they do have same correspondence within their respective ranges of test points.

The orientation of the rake is shown pictorially in Figures 1 through 6 for the various test runs. Figure 7 presents a scaled drawing of the model with reference to the three-axis coordinate system.

TABLE 1	1 41 412 626		
OUTLINE OF WAKE IN	VESTIGATIONS Configuration Code		Base- line
Build-up to Baseline	1980-1990-1983		
1. Nacelles removed	K ₁₃ +H ₁ -N	149	150
2. Blades off, rotating hub	K ₁₃ -M+H _{1.0}	160	156
3. " , non-rotating hub	K ₁₃ -M+H _{1.0}	158	156
4. " " , hub off	K ₁₃ -M-H _{1.0}	159	156
Basic Configuration	alliely among a		
1. Wake Explorations near Empennage	see 18 s sous 1		
(a) 15" Long. + traverse at T/R C.L.	K ₁₁	111	
(b) 9" Vert. + " above T/R "	•	112	
(c) 2" " in vortex (d) 8" " (continue 112)	"	1113	
(e) 13" " behind stab.	n and the second	115	
(f) Lateral traverse, left stab.	• (25) (10)	116	
(One T.P. only)	"	117	
(g) Same continued (h) Same continued (One T.P. only)	11	118	
(i) Lateral traverse right stab.	" 0	119	
(j) T/R effect on wake	$K_{11} + T_2^0$	121	115
2. Climb/Descent Studies	- 100 A 100 A		
(a) Climb 900 FPM	K _{1 1}	135	
(b) Descent 800 FPM	• (S. 20)	136	
Effect Of Hub Caps	esta Postilla V		
1. Solid Caps on Canister	er Liggin Heles - 7		
(a) 7.6" diam. 2.17" ht. soft Pitch Arms	K ₁₁ -H _{1.0} +H _{1.2}	137	136
(b) 7.6" diam. 2.17" ht. stiff Pitch Arms	K ₁₃ +H _{1.2}	153	156
(b) 7.6" diam. 2.45" ht. flt. test config.	$K_{13} + H_{1 \cdot 2 \cdot 1} + I_{1} + E_{1 \cdot 0}$	207	188

TABLE 1 (CONTINUED) OUTLINE OF WAKE INVESTIGATIONS Configuration Run Base-Description Code* No. line Effect of Hub Caps (Continued) 2. Solid Caps Raised Above Canister (a) 7.6" diam. 2.45" ht. 70" $H_{1.2.2}+I_1+E_{1.0}$ 208 188 depth, .55 gap (b) 10.0" diam. 3.25" ht. 1.55" H_{1.8.1}+I₁+E_{1.0} 189 188 depth, .50" gap (c) 10.0" diam. 4.125" ht. H_{1.8.2}+I₁+E_{1.0} 190 188 2.05" depth, .875" gap (d) Repeat of 189 210 188 3. Open Caps Without Underbody (a) 10.0" diam. 1.25" gap, blades $H_{1.0.2}^{+1.0.2} + I_{1.0}^{+1.0}$ (b) " " gap, no $H_{1.0.1}^{1.0.2} - M_{1.0.1}^{+1.0}$ 193 188/166 158 166 blades 2.05" gap,blades $H_{1.14.1}+I_1+E_{1.0}$ (c) 211 188 1.75" gap, no (d) 165 158 $H_{1.0.1}-M$ blades 1.87" gap,blades H_{1.0.3}+I₁+E_{1.0} 191 188 H_{1.7.1}-M (f) 16" diam. 2.00" gap, blades 168 156/167 (g) 167 gap, no 158 blades 4.00" gap, blades (h) H_{1.7.2} 169 156 4. Open Caps with Underbody (a) 7.6" diam. 1.25" gap H_{1.11.1}+I₂+E_{1.0} |194 188 (b) H1.11.1+I2+E4.0 198 188 (c) center 202 194 $H_{1.11.2}+I_2$ post (d) 10.0" diam. .5" gap, no 164 158 H1.5.1-M blades 1.25" gap, no (e) 161 158 H1.5.2-M blades (f) 2.0" gap, no 163 158 H1.5.4-M blades 4.0" gap, no (g) 162 158 H_{1.5.3}-M blades (h) 1.25" gap H1.5.2 154 156/161

*Basic Code is K13.

TABLE 1 (CONTINUED)

OUTLINE OF WAKE INVESTIGATIONS

Description	Configuration Code*	Run No.	Base- line
5. Miscellaneous Hub Covers	1300 A Mari		
(a) Hub fairing 16" diam.(b) Wham-O-Frisbee 10" diam.(c) Fab. glass Frisbee 16" diam.	H _{1.3} H _{1.9.0} +E _{1.2} H _{1.9.1} +E _{1.2}	151 182 183	150 181 181
Effect of Air Ejectors	as 'A loss 'Al elo	2 36	1 (1)
Basic system no blowing " " 40 psi " " 150 psi Wide chord shroud 40 psi W/C shroud w. lip 40 psi Same Contoured Parallel 150 psi Bifurcated duct 0 psi " " 40 psi " " 150 psi	H _{1.0} +E _{1.0} H _{1.0} +E _{2.5.1} H _{1.0} +E _{3.5.2} H _{1.0} +E _{3.5.4}	174 175 176 184 187 203 204	156 156/172 156/173 156/173 156/173 156/174 156 156/203
Air Ejectors with Open Hub Caps with Underbodies			
1. 7.6" diam. 1.25" gap, 0 psi 2. " " " " 20 psi 3. " " " 40 psi 4. " " " 150 psi 5. " " " 0 psi 6. " " 40 psi 7. " " 150 psi 8. Same with center post 9. 10.0" diam. 2.0" gap wide ch'd. shroud (150 psi)	H _{1.11.1} +1 ₂ +E _{1.0} """ H _{1.11.1} +I ₂ +E _{4.0} """ H _{1.11.2} +I ₂ +E _{4.6} H _{1.5.4} +E _{2.5.1}	195 196 197 198 199 200 201	188/172 188 188/173 188/174 188/194 188/196 188/196 188/200 156/176
Effect of Wings and Misc.			
1. Wings (a) Nacelle-mounted stub wing (b) Single slotted flapped wing (c) Dougle slotted flapped wing (d) Boom-mounted stub wing	H _{1.0} +W _{1.0} +E _{1.1} H _{1.0} +W _{3.0} +E _{1.0} H _{1.0} +W _{2.0} +E _{1.0} H _{1.0} +W _{4.0}	178 180 179 186	181 181 181 156

TABLE 1 (CONTINUED)

OUTLINE OF WAKE INVESTIGATIONS

	Description	Configuration Code*	Run No.	Base- line
2.	Crown Fairings (a) Flat top behind shaft (b) Round top behind shaft (c) Extended flat top fairing (d) Flat top + 16" cap, 4" gap (e) Forward fairing/nacelle fairing	K _{1 1} +D ₁ K _{1 1} +D ₂ H ₁ +D ₄ H _{1 • 7 • 2} +D ₄ P _{1 • 0}	140 141 170 171 152	138 138 156 170 156
3.	Surface Devices (a) Vortex generators (b) Guidevane between nacelles (c) Longitudinal strakes (d) 14% porosity spoiler	K ₁₁ +VG ₂ , 1 K ₁₁ +FV ₁ H _{1•5,3} +S ₄ K ₁₁ +X ₁	139 142 155 143	138 138 156 138
			250 1536 1	
		m. 2.0" gap stds 50 path tys and skids	36 F	
		nin cen bedenmen M Azagali badanis M Dempili badanis	25 (30.84 (30.01)	

*Basic Code is Kl3 unless noted otherwise.

	TAIL	ROTOR	Off	:	=			=				oo	Off	
	MR HT.	p/q	8	=	=	-	=	=		=	=	=	=	
	MODEL	. 4	-2.0		•	•		-	-			=	4.5	-2.0
	MODEL	90	0.9	=		=	=	=	=	•		=	-6.0	0.9
AKE	DISK	rbg.	&	=			=	=	•	•	=	=	-	•
AS HE HUB W	RPM	MR/TR	1433/0	=	=	=	=	=		•		1433/		=
TABLE 2 LIST OF TEST RUNS STIGATIONS OF THE	Vrun	KNOTS	80			•	=	=		•	=	=		
TABLE 2 LIST OF TEST RUNS BASIC INVESTIGATIONS OF THE HUB WAKE	CONFIGURATION		K ₁₁ /15" Long. wake traverse at TR center line	" /9" Vert. wake traverse above TR center line	" /2" Vert traverse through MR vortex	" /8" Vert. traverse below TR center line	" /13" Vert. traverse behind stabilizer	" /Lateral traverse - left stabilizer	" /116 continued	" /116 continued	" /Lateral traverse - right stabilizer	<pre>K₁₁+T₂/Effect of tail rotor flow on wake</pre>	K ₁₁ /Wake in 900 fpm climb	" /Wake in 800 fpm descent
	RUN	NO.	111	112	113	114	115	116	117	118	119	121	135	136

NS	EVALUATION OF WAKE-ALTERING DEVICES
R	ER
TEST	KE-ALT
OF	WA
ST (OF
3	EVALUATION
	LIST OF TEST RUNS

RUN	CONFIGURATION/CONDITION	VTUN	RPM	DISK	MOL	MODEL	MR HT.	TAIL
.O.		KNOTS	MR/TR	pst.	• D	• 4	p/q	ROTOR
137	Kll-Hl.0+Hl.2/Effect of 7.6 inch diam. solid hub cap	80	1433/0	8	9	-3.8	8	Off
138	Kll/Repeat of base run		=	=				
139	K ₁₁ +VG _{2.1} /Effect of vortex gener- ators on aft crown	•	=	=	=	=	2	=
140	<pre>Kll+Dl/Flat-topped "doghouse" fair- ing on aft crown</pre>		=	=	•	-	=	
141	$K_{11}^{+}D_2/Rounded$ -top fairing	=	=			=		
142	<pre>K₁₁+FV₁/Deflection vane on crown between nacelles</pre>	•		2	-		•	
143	$K_{11}^{+X}/Variable$ porosity spoiler				=	=		
149	K ₁₃ +H ₁ -N ₁ /Effect of nacelles off also acd stiff pitch arms (K ₁₃)	60	1075/0	4.5				
150	$K_{13}^{+}H_{1}/60$ knot baseline	•		E	=			
151	K ₁₃ +H _{1.3} /16 inch diam, helmet fair- ing	=			=			-
152	$K_{13}^{+P}_{1.0}/^{Py}$ lon and intake fairings	80	1433/0	80			=	
153	$K_{13}^{+H}_{1.2}$ /Repeat 137 with K_{13} pitch arms				=		=	
								T

TABLE 2 (CONTINUED)
LIST OF TEST RUNS

EVALUATION OF WAKE-ALTERING DEVICES

	CONFIGURATION/CONDITION	Vrun	RPM	DISK	ANG	MODEL	HT.	TAIL
		KNOTS	MR/TR	psf	•	•	h/d	ROTOR
K13+H]	K13+H1.5.2/10" open hub cap, 7" underbody, 1.25"gap	80	1433/0	8	9	-3.8	8) jjo
K13+H	K ₁₃ +H _{1.5.2} +S ₄ /Same as 154 except strakes on aft crown	:		=	•	•		
K13+	Kl3+H1.0/Baseline with Kl3,i.e., stiff pitch arms				=	*	=	
K13-	K ₁₃ -M+H _{1.0} /Wake studies with blades off, hub not rotating		0/0				=	•
K13-	K ₁₃ -M-H _{1.0} /Wake studies with hub of		•		=	=	=	
K13-	K ₁₃ -M+H _{1.0} /Same as 158 except hub is rotating		1433/0		•			
K13-	K ₁₃ -M+H _{1.5.2} /Repeat of 154 without blades		0/0			=	=	:
K13	K ₁₃ -M+H _{1.5.3} /Same as 161 except 4"			•		=	=	
K13	K ₁₃ -M+H _{1.5.4} /Same as 161 except 2" gap	•					=	
K13-	K ₁₃ -M+H _{1,5,1} /Same as 161 except 0.5" gap			•			•	:
^K 13-	K ₁₃ -M+H _{1.0.1} /10" open hub cap,no under- body,same cap vert.position as Run 154					=	=	
K13	K ₁₃ -M+H _{1.0.2} /Same as 165 with cap lowered by 0.5"					=	=	

		EVALUATION OF WAKE-ALTERING DEVICES
(a)	JNS	NG
NE	R	RI
II	ST	TE
00	TE	-AI
7	F.	KE-
E	2	WA
TABLE 2 (CONTINUED)	LIST OF TEST RUNS	OF
		LON
		AT
		ALU
		EV

K13-M+H1.7.1/16" open cap K13+H1.7.1/Blades on, sam config. as 167 Config. as 167 K13+H1.7.2/16" open cap, 1 body, 4" gap K13+H1.0+D4.0/Extended flatering on 2 K13+H1.0+E1.0/Same fair: 2 Same cap 3 K13+H1.0+E1.0(0psi)/Basic tor zero blowing baseline K13+H1.0+E1.0(150 psi)/Same K13+H1.0+E1.0(150 psi)/Same K13+H1.0+E2.5.1(150 psi)/E with 150 psi K13+H1.0+E2.5.1(150 psi)/E with 150 psi K13+H1.0+E2.5.1(150 psi)/E with 10 psi	KNOTS MB/mB LDG.		, no under- 80 0/0 8 6-3.8 ~ Off	e cap " 1433/0 " " " " ."	no under-""""""""	at top " " " " " " aft crown	ing as 170, " " " " " " as 169	air ejec- " " " " " " "	e as 172 " " " " " " supply	me as 172 " " " " " supply	jector with " " " " " " 40 psi	same as 174 " " " " " supply)/Same as " " " " " " 1ike 163	/Nacelle " " " " " " wing
VTUN KNOTS er- 80 " " " " 170 1174 " " " " 174 " " " 174 " " " " 174 " " " " 174 " " " " 174	RPM DISK	MR/TR P	0/0	133/0	a			=	=	=		-		
" 1 1 1 1 1 1 1 1 1					:									
	CONFIGURATION/CONDITION		cap,	on, same . as 167	K ₁₃ +H _{1.7.2} /16" open cap, no under- body, 4" gap	K ₁₃ +H _{1.0} +D _{4.0} /Extended flat top fairing on aft crown	0/Same fairing as same cap as 169	asic air eline	/Same as psi suppl	K ₁₃ +H _{1.0} +E _{1.0} (150 psi)/Same as 172 with 150 psi supply	(40 psi)/Ejector	K ₁₃ +H _{1.0} +E _{2.5.1} (150 psi)/Same as 174 with 150 psi supply		K ₁₃ +H _{1.0} +W _{1.0} +E _{1.1} (0 psi)/Nacelle mounted wing

8	TABLE 2 (CONTINUED)	(CONTINUED)	~ E					
	EVALUATION OF WAKE-ALTERING DEVICES	ALTERING	DEVICE	ξ O				
RON	CONPIGHBANTON/CONDINION	VTUN	RPM	DISK	MODEL	MODEL	MR HT.	TAIL
0		KNOTS	MR/TR	LDG.	90	•	þ/q	ROTOR
179	K ₁₃ +H _{1.0} +W _{2.0} +E _{1.0} (0 psi)/Double slotted flapped wing	80	1433/0	8	9	-3.8	8	OÉF
180	K ₁₃ +H _{1.0} +W _{3.0} +E _{1.0} (0 psi)/Single slotted flapped wing	=	E	-	•	•		=
181	K ₁₃ +H _{1.0} +E _{1.2} (0 psi)/Baseline with ejector tube moved aft		=	*	=	=	=	=
182	K ₁₃ +H _{1.9.0} +E _{1.2} (0 psi)/Standard 10" frishee				=	=	=	£
183	K ₁₃ +H _{1.9.1} +E _{1.2} (0 psi)/16"·fabri- cated frisbee					:		=
184	K ₁₃ +H _{1.0} +E _{3.5.2} (40 psi)/Wide chord with lip at 40 psi			=	=	=		•
185	K ₁₃ +H _{1.0} +E _{3.5.2} (150 psi)/Same as 184 with 150 psi air		=	-	=	=		=
186	Kl3+Hl.0+W4.u/Boom mounted stub wing	u	2		=	=	=	•
187	Kl3+Hl,0+E3,5,4 (150 psi)/Like 185 with modified shroud					:	•	•
188	K ₁₃ +H _{1.0} +I ₁ +E _{1.0} (0 psi)/Baseline with I, instr. ring		=		=	=	=	•
189	0 1			=	E .	2	=	=
190	Kl3+Hl.8.2+Il+El.0 (0 psi)/Same as	•			=			•

EVALUATION OF WAKE-ALTERING DEVICES NODEL HR		TABLE 2 ((CONTINUED)						
CONFIGURATION/CONDITION WARE-ALTERING DEVICES HADDEL MADEL MADEL MADEL MATER M		LIST OF	TEST RU	18					
CONFIGURATION/CONDITION		EVALUATION OF WAKE-	ALTERIN	3 DEVICE	ß				
No. No.	RGN	NOT#TONOC/NOT#ERIBRATION	Vrun	RPM	DISK	MOL	EL	MR HT.	TAIL
K13+H1.0.2+I1+E1.0 (0 psi)/10" cap, 80 1433/0 8 6 -3.8 8 8 8 8 8 8 8 8 8	08	NOTITION (NOTITION AND AND AND AND AND AND AND AND AND AN	KNOTS	MR/TR	rpg.	• g	•	h/d	ROTOR
K13+H1.02±I1+E1.0 (0 psi)/10" cap, """"""""""""""""""""""""""""""""""""	191	+E1.0 (0 psi)/10" dy, 1.87" gab	80	1433/0	8	9	-3.8	8	Off
K13+H1.11.1+I2+E1.0(0 psi)/7.6" cap, """"""""""""""""""""""""""""""""""""	193		=	=	=	=	=	=	=
Kl3+H].11.1+I2+E].0(20 psi)/Same as " " " " " "	194		=	=	=	=		=	=
K13+H1.11.1+12+E1.0(40 psi)/Same as " " " " " " " " " "	195	psi)/Same	=	=	=	=	=	=	-
K13+H1.11.1+T2+E1.0(150 psi)/Same as " " " " " " " " " " " " " " " " " "	196	psi)/Same	-	=	=	=	=	=	-
K13+H1.11.1+I2+E4.0 (0 psi)/Same as " " " " " " " " " " " " " " " " " "	197	2+E1.0(150 psi)/Same 50 psi air			=		=	=	=
K13+H1.11.1+I2+E4.0 (40 psi)/Same as " " " " " " " " " " " " " " " " " "	198	Kl3+H1.11.1+I2+E4.0 (0 psi)/Same as 194 except blowing tube 2" aft				•		=	=
R13+H1,11.1+I2+E4,0 (150 psi)/Same	199					•		=	
K13+H1.11.2+I2+E4.0 (150 psi)/Same " " " " " " " " " " " " " " " " " " "	200	K13+H1,11,1+I2+E4.0 (150 psi)/Same as 198 with 150 psi air		10 TO					•
$\kappa_{13^+H_1,11,2^+I_2/Baseline}$ with I_2 and " " " " " " " no blowing tube $\kappa_{13^+H_1,0^+E_5,0}(0\text{ psi})/\text{Bifurcated air}$ " " " " " " " " auct baseline	201	Kl3+Hl.11.2+I2+E4.0 (150 psi)/Same as 200 except center support cap				2		•	•
K ₁₃ +H _{1.0} +E _{5.0} (0 psi)/Bifurcated air " " " " " duct baseline	202			1803 PW 318		=	•	=	=
	203	(0 psi)/Bifurcated ine		=	=	=	=		=

	TABLE 2 (CONTINUED) LIST OF TEST RUNS EVALUATION OF WAKE-ALTERING DEVICES	(CONTINUED) TEST RUNS ALTERING	as S DEVICE	ξ O				
RON	MOTHT GMOON WOTH REGISTER AND A	Varin	RPM	DISK	MODEL	MODEL	MR HT.	TATE
NO.	CONFIGURATION/ CONDITION	KNOTS	MR/TR	LDG.	8	•	p/q	ROTOR
204	K ₁₃ +H _{1.0} +E _{5.0} (150 psi)/Bifurcated duct with 150 psi air	80	1433/0	8	9	-3.8	8	Off
205		=		=) (C.
207	K ₁₃ +H _{1.2.1} +I ₁ +E _{1.0} (0 psi)/7.6" solld cap, no gap	<u>.</u> ت		=		=	•	
208	K ₁₃ +H _{1.2.2} +I ₁ +E _{1.0} (0 psi)/Same as 207 except 0.55" gap			=	=	2	=	=
210	K ₁₃ +H _{1.15.1} +I ₁ +E _{1.0} (0 psi)/Repeat of 189	-	•	=	=	•	-	
211	K13+H1.14.1+I1+E1.0 (0 psi)/Like 189 and 210 except cap is open			=				
				5 E		0 (1) 1 (1) 1 (1)	731)	
	134		\$27					

TABLE 3

INDEX TO RAKE POSITIONS

RUN NUMBER	POINT	WATER	MODEL STATION	BUTT	LOCATION
111	20	53.5	103.1	-7.25	1
	21 22		105 0		
	24		105.0		
	26		109.0		
	28		111.0		
	30	"	112.9		
	32		114.9		
	34		116.9	"	
	36		118.9		
112	2	48.9	107.3	-7.25	1
	2 4 6 8	50.8		"	
	6	52.7	103.3		
	10	54.5 56.2			
	12	57.2		•	1 1 1 1 1 1 1 1
113	2	51.7	103.3	-3.25	1
	2 4	52.3	"		
	6 8	52.8			14 74
		53.3			
	10	53.9			
	11	53.3			
114	2 4	44.5	103.0	-3.25	1
	4	46.4			
	6 8	48.2			
	10	51.9	•		
115	3	52.9	124.7	-3.25	1
	4	52.0	"		
	10 12	50.0	"		
	9	48.0			
	10	46.0			
	12	44.1			
	14	44.1 42.1 53.0			
	18	54.0			
	20	55.0			Zi .

TABLE 3 (CONTINUED) INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER	MODEL STATION	BUTT	LOCATION FIGURE
116	7	36.9	100.5	-17.5	1
117	2 4 6 8 10	37.6 37.3	100.5	-16.0 -14.0 -12.0 -10.0 - 8.0	1
118	2	37.6	100.5	- 6.0	1
119	2 5 8 9 14 16 20 25	37.3 "" "" 51.5 52.3	99.6 "" 102.5 101.7	+ 6.0 8 10 14 16 17.5 -17.5	1
121	3 4 6 8 10	62.9 53.5 50.1 46.0 42.1	129.0	+ 5.7	2
135	2 4 6 8 10 12 14	56.9 54.5 52.5 50.5 48.5 46.5 44.5	106.3	- 5.7	3
136	2 4 6 8 10 12 14 17 18 19	56.5 54.5 52.5 50.6 48.5 46.5 44.5 37.1 39.0 41.0	104.0	- 8.0	4

TABLE 3 (CONTINUED) INDEX TO RAKE POSITIONS

 1		Τ			
RUN NUMBER	POINT	WATER	MODEL	BUTT	LOCATION
137	3 5 7 9 11 13 15 17	38.7 39.9 42.0 44.0 46.0 48.0 50.0 52.0	98.4 100.5 103.6	- 8.0 "" ""	5
138-41, 143	2 3 4 5 6 7 8 9	38.8 40.0 42.0 44.0 46.0 48.0 50.0 52.0 54.0	98.4 100.5 103.6	- 8.0 " " "	5
142	7 8 9 10 11 12 13 14 15 16	37.8 40.2 42.0 44.0 46.0 48.0 50.0 52.0 54.0 56.8	98.4 " 100.5 103.6	- 8.0 "" ""	5
		0-101	8.05 2.05 2.05 2.05 2.05 2.05 2.05 2.05 2		

TABLE 3 (CONTINUED)

INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER	MODEL STATION	BUTT	LOCATION FIGURE
149-151	2 3 4 5 6 7 8 9	38.8 40.0 42.0 44.0 46.0 48.0 50.0 52.0 54.0	98.5 100.6 103.5	- 8.0	5
152-6, 158 161-4, 166 167, 169-71 175, 177-9 180,182,184 186-8, 190 191,193,194 196,198,201 204,207,208 211	2 3 4 5 6 7 8 9	42.9 44.9 46.9 48.9 50.9 52.9 54.9 56.9	97.9 100.6 104.6	0.0	6
159	1 2 3 4 5	54.9 52.9 50.7 48.6 46.7	104.6	0.0	6
160,203	5 6 7 8 9 10	42.9 44.9 46.9 48.9 50.9 52.9 54.9	97.9 100.6 104.6	0.0	6
165	3 4 5 6 7 8	44.9 42.9 46.9 48.9 50.9 52.9	97.9 100.6 104.6	0.0	6

TABLE 3 (CONTINUED) INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER LINE	MODEL STATION	BUTT	LOCATION FIGURE
168, 183	4 5 6 7 8 9	42.9 44.9 46.9 48.9 50.9 52.9 54.9	97.9 100.6 104.6	0.0	6
172	3 4 6 7 8 9 10	42.9 44.9 44.9 46.9 48.9 50.9 52.9 54.9	97.9 " 100.6 104.6	0.0	6
173,174,176 185,195,197 199,200,205 210	1 2 3 4 5 6 7	42.9 44.9 46.9 48.9 50.9 52.9 54.9	97.9 100.6 104.6	0.0	6
181	2 3 4 5 6 7 9 10 11 12 13	42.9 44.9 46.9 48.9 50.9 52.9 54.9	97.9 100.6 104.6	0.0	6
		3. 351 A. A.,	0.00 0.00 0.00 0.00 0.00		

TABLE 3 (CONTINUED)

INDEX TO RAKE POSITIONS

RUN NUMBER	TEST POINT	WATER LINE	MODEL STATION	BUTT LINE	LOCATION FIGURE
189	29 30 31 32 33 34 35 36 37 38 39	42.9 44.9 46.9 48.9 50.9 50.9 52.9 54.9	97.9 100.6 " 104.6 100.6 104.6	0.0	6
202	3 4 5 6 7	43.4 44.9 46.9 48.9 50.9	97.9 100.6 104.6	0.0	6
				76 Z	
				the Add	a recent public
				125 - 513 Mail - 134 (33 - 184)	GUTS-SPINATOFE.

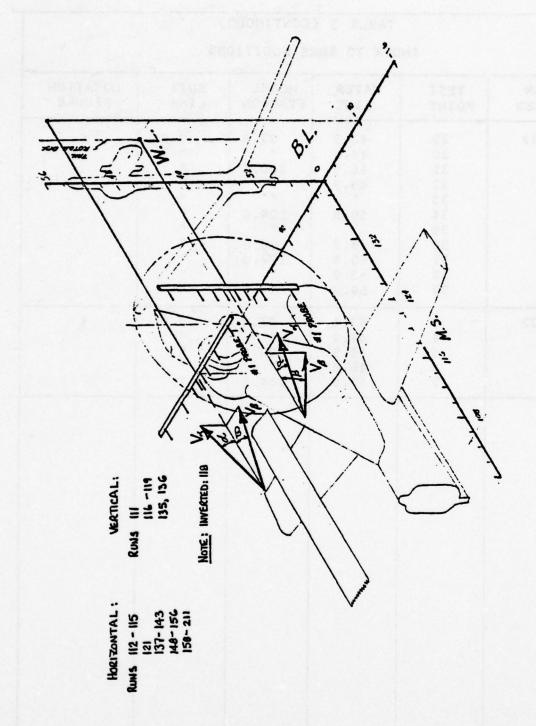


FIGURE 1 - RAKE ORIENTATION DIAGRAM

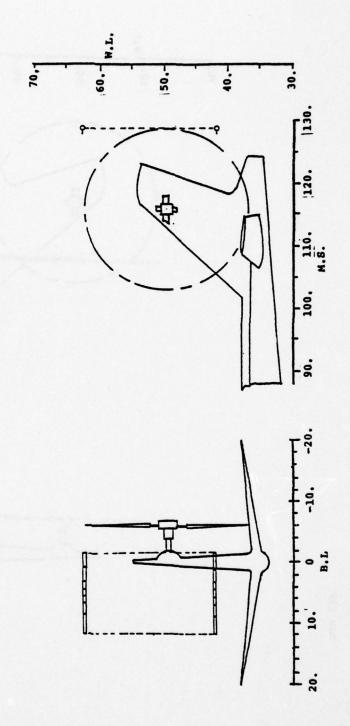


FIGURE 2 -HOT FILM RAKE LOCATIONS

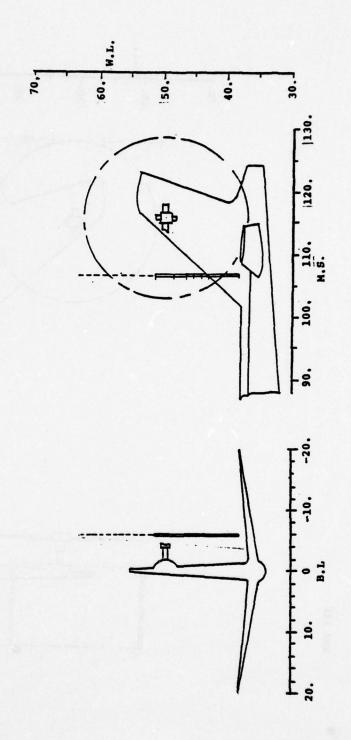


FIGURE 3 -HOT FILM RAKE LOCATIONS



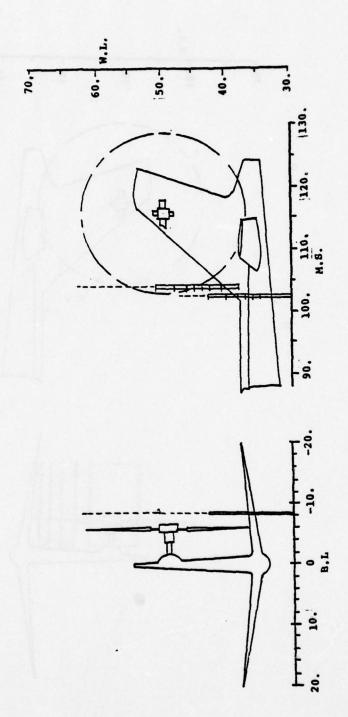


FIGURE 4 -HOT FILM RAKE LOCATIONS

RUN 137, 138, 139, 140, 141, 142, 143, 148, 149, 150, 151

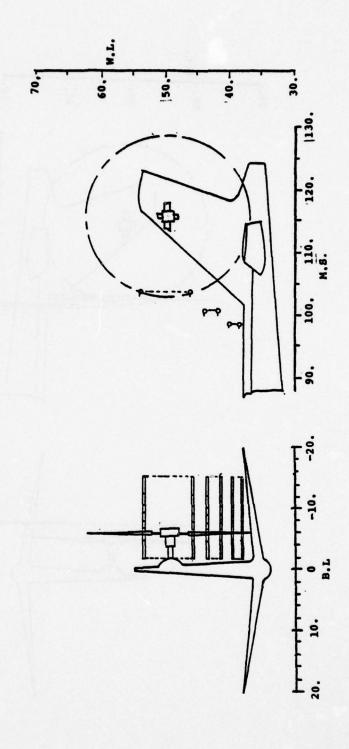


FIGURE 5 -HOT FILM RAKE LOCATIONS

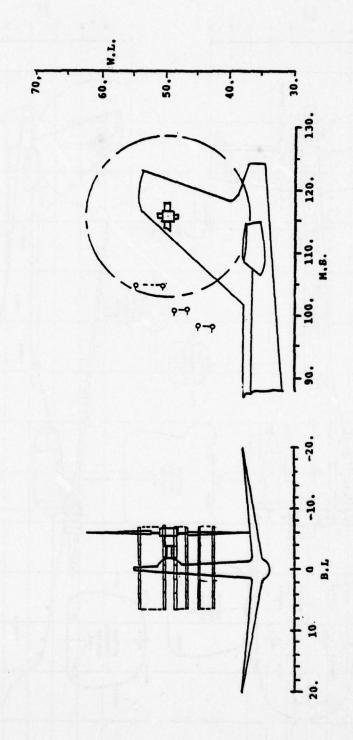


FIGURE 6 -HOT FILM RAKE LOCATIONS

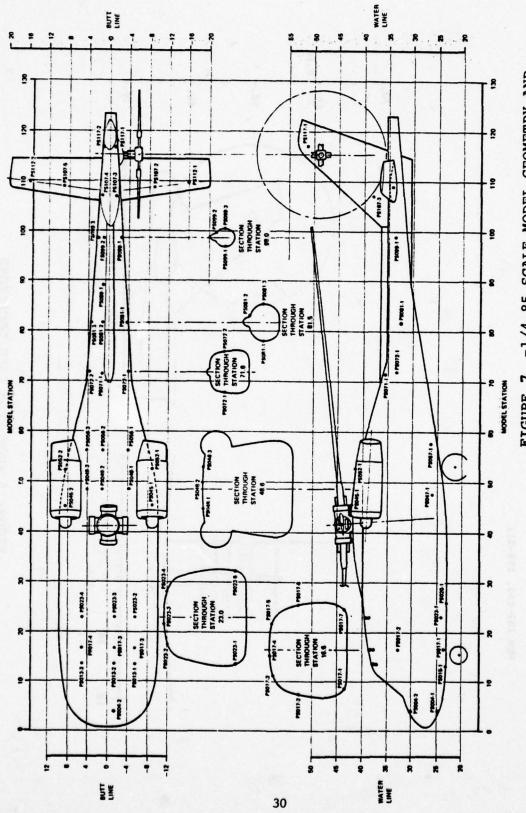
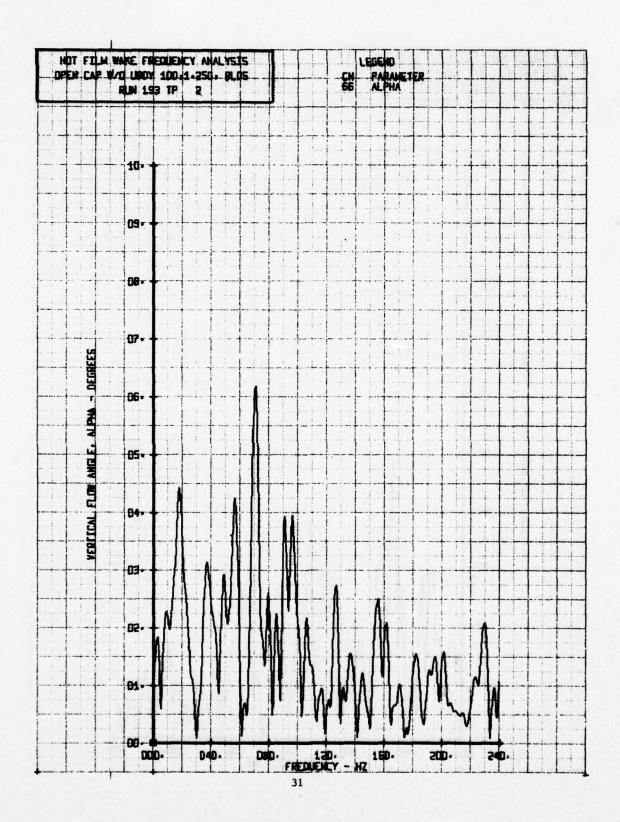
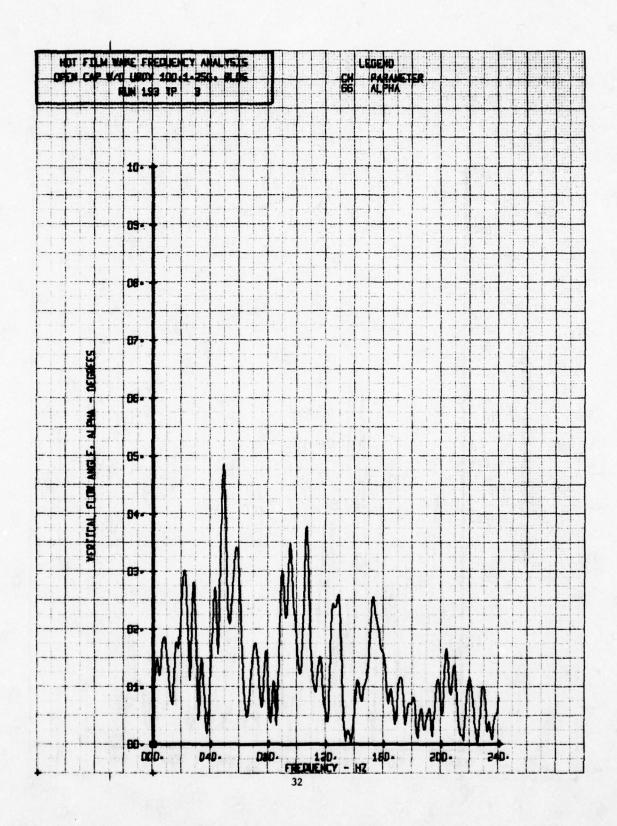
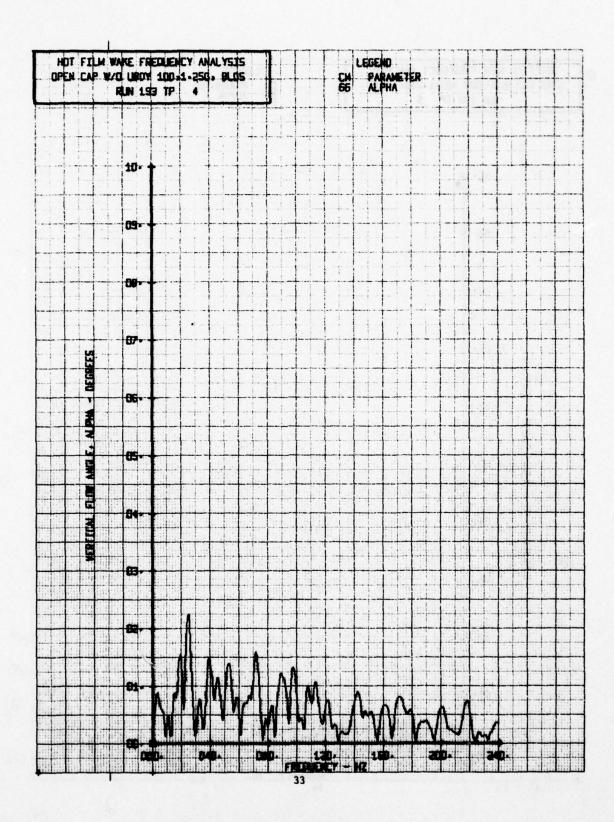
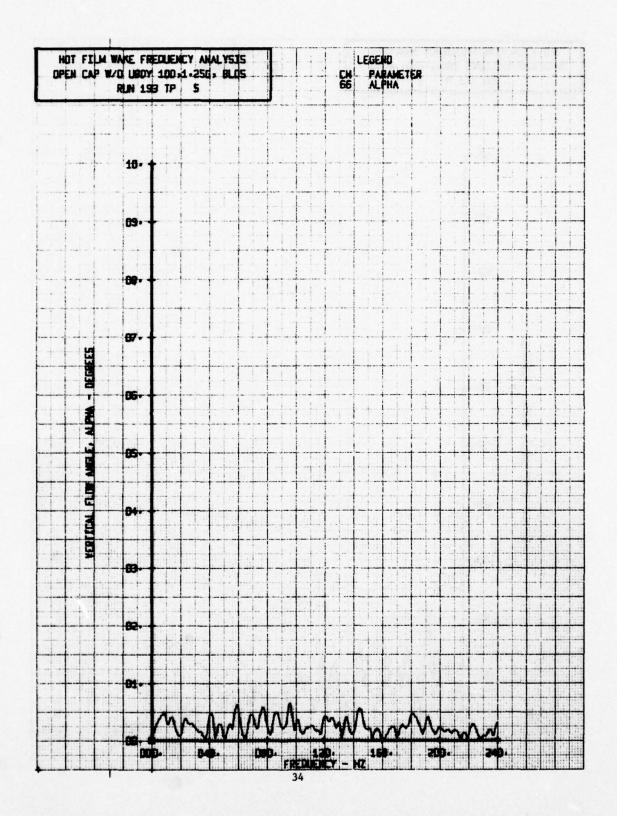


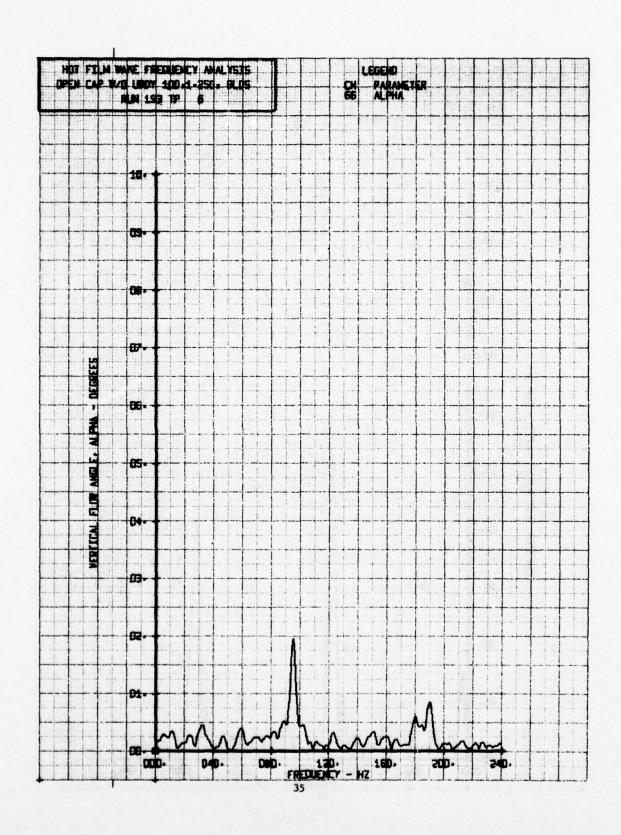
FIGURE 7 -1/4.85 SCALE MODEL GEOMETRY AND SURFACE PRESSURE TRANSDUCER LOCATIONS

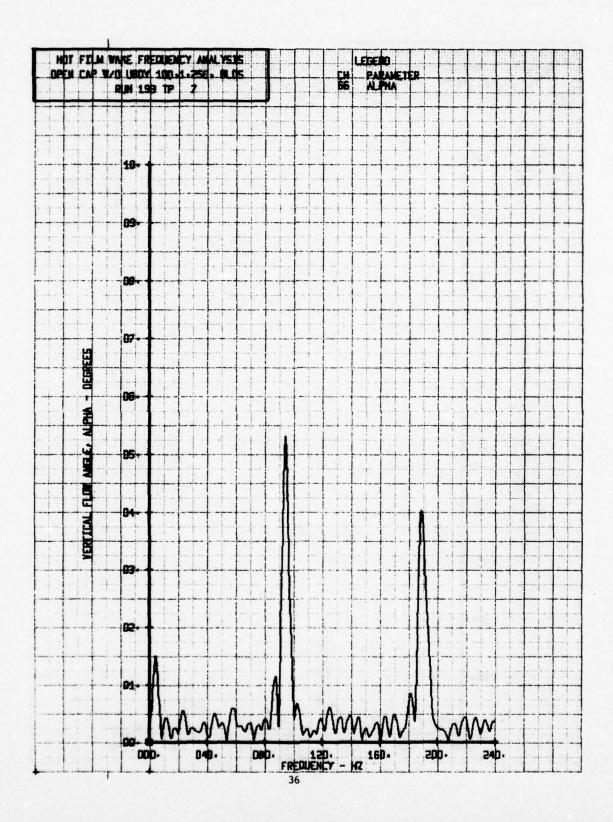


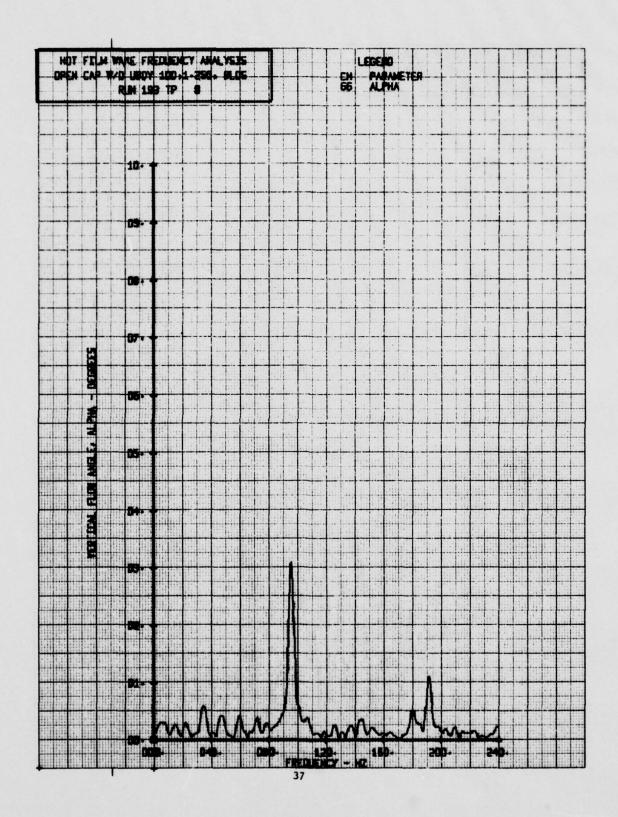


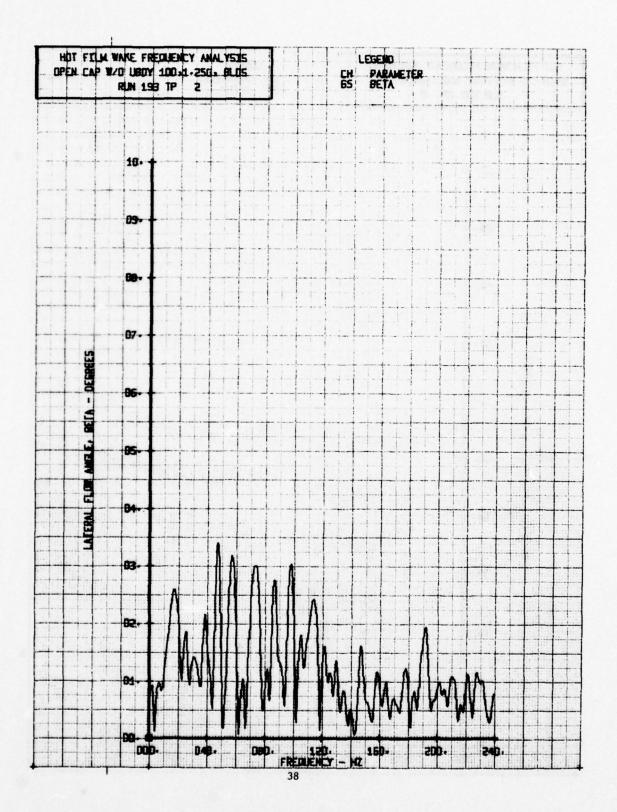




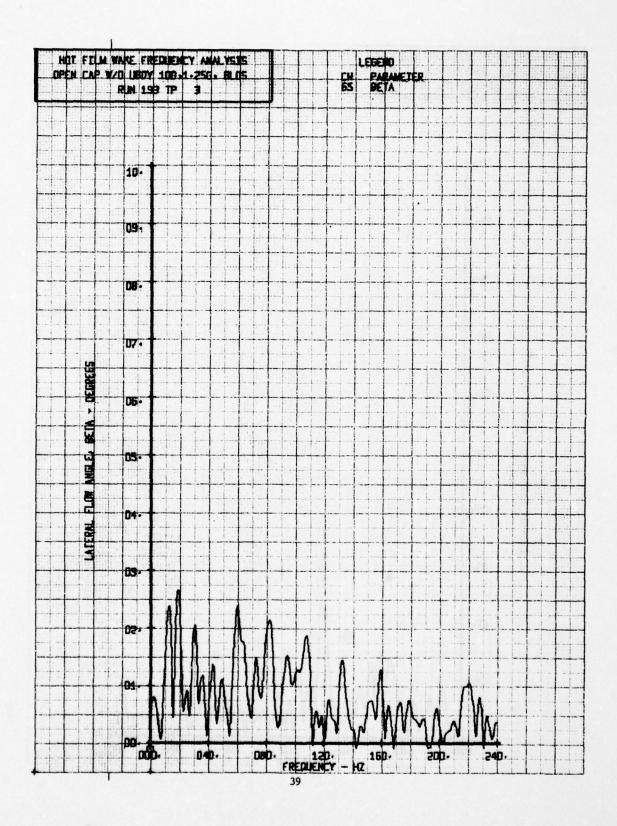


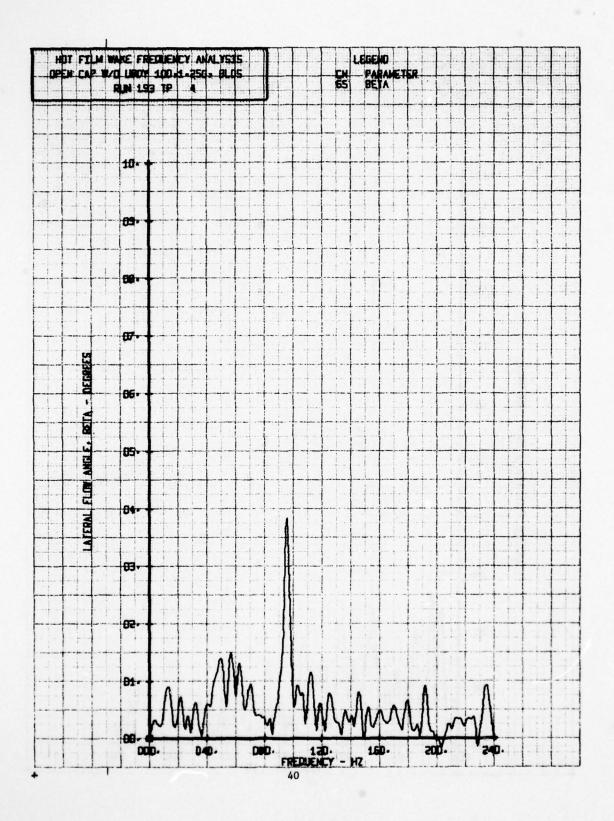


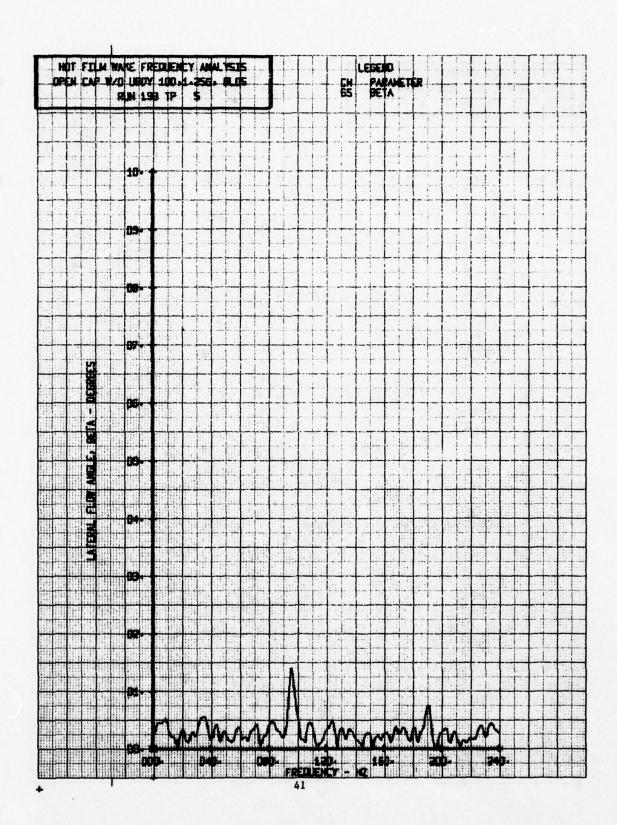


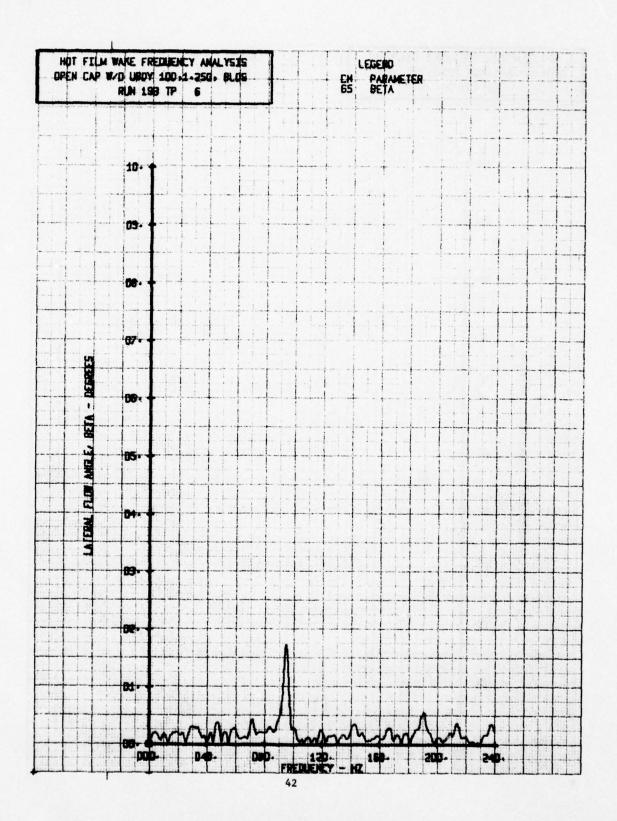


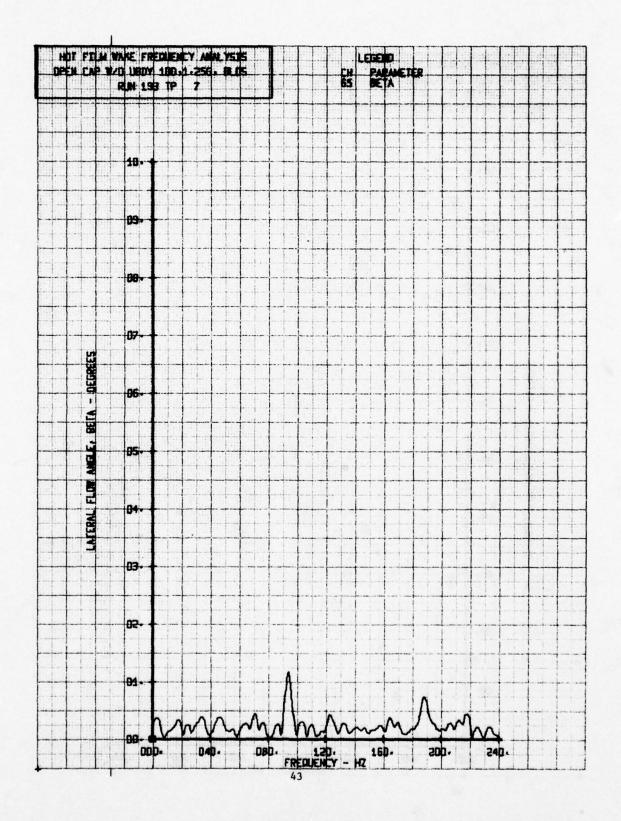
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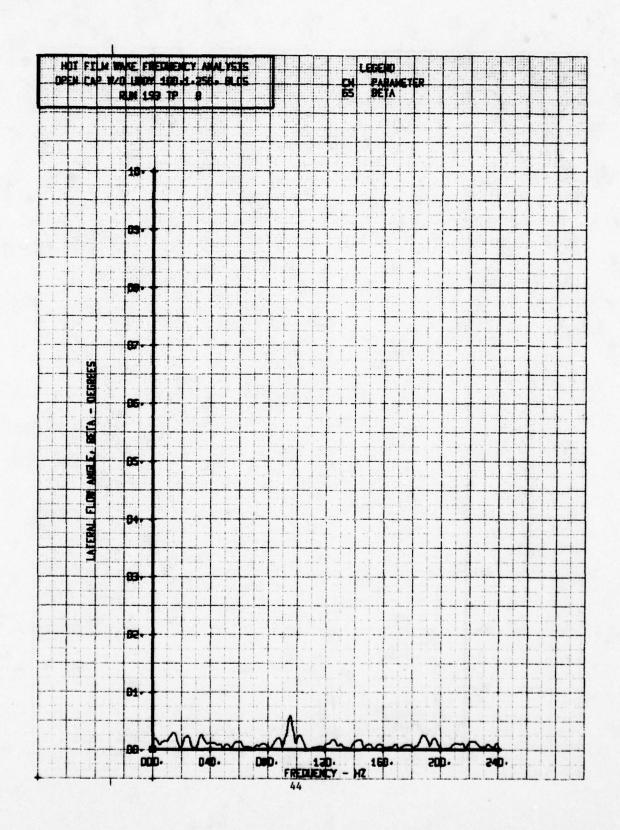


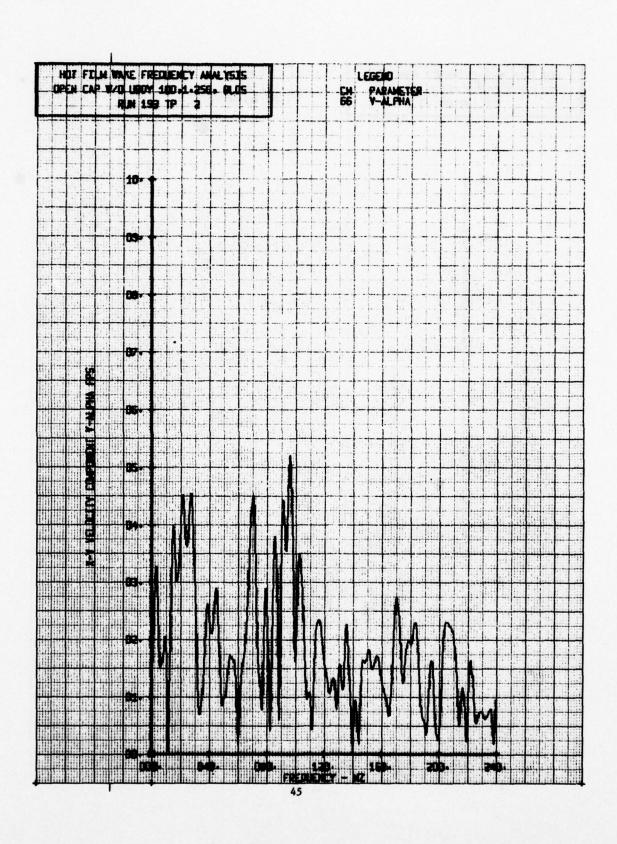


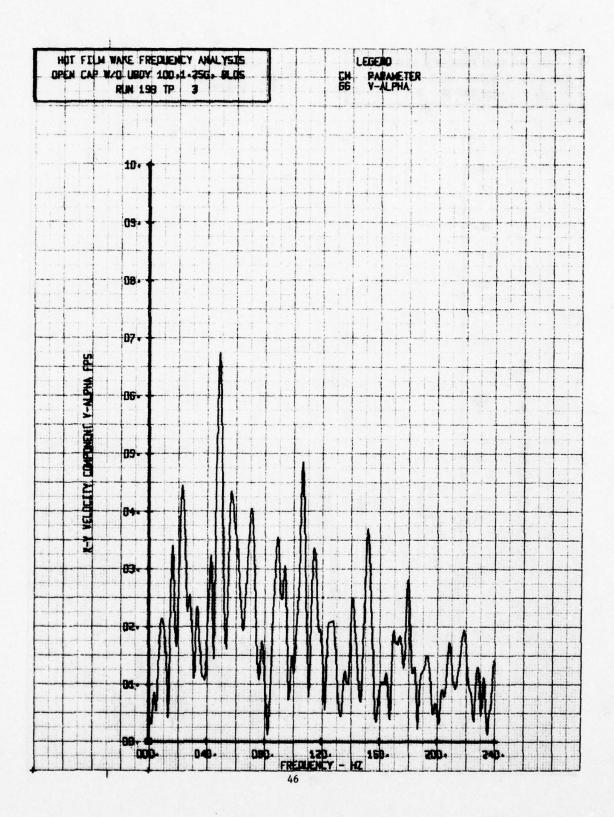


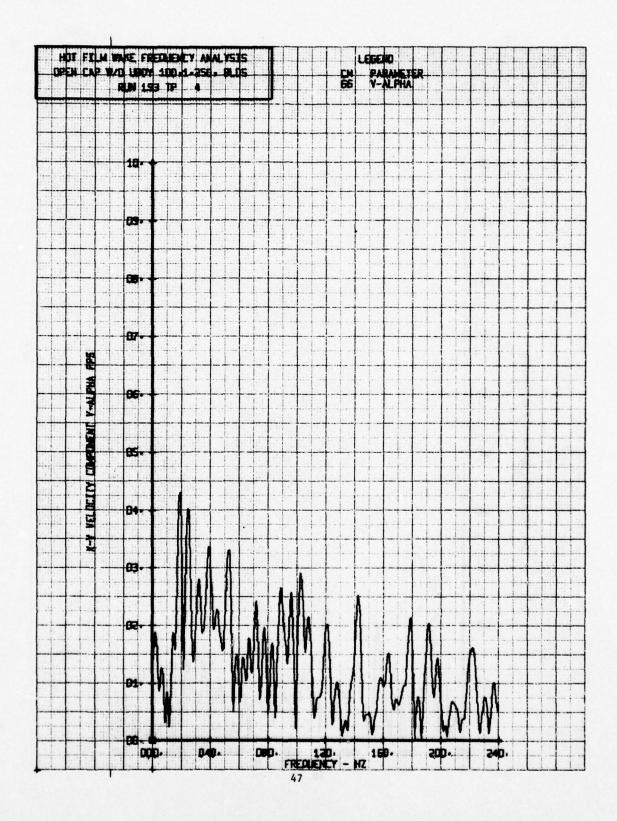


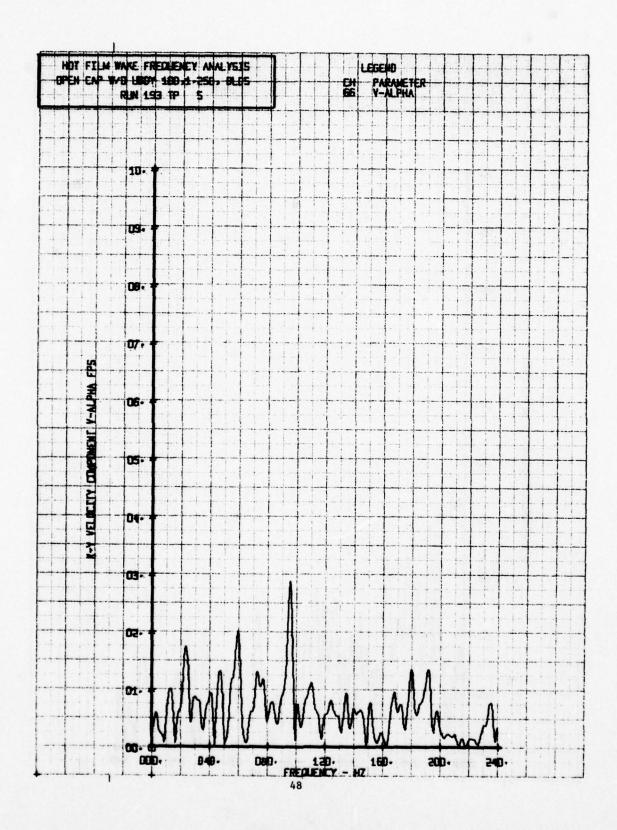


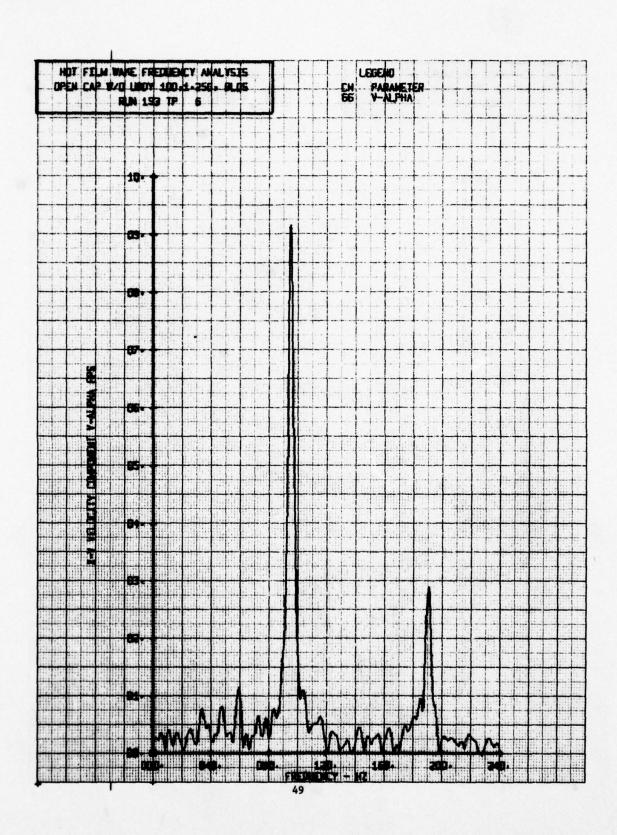


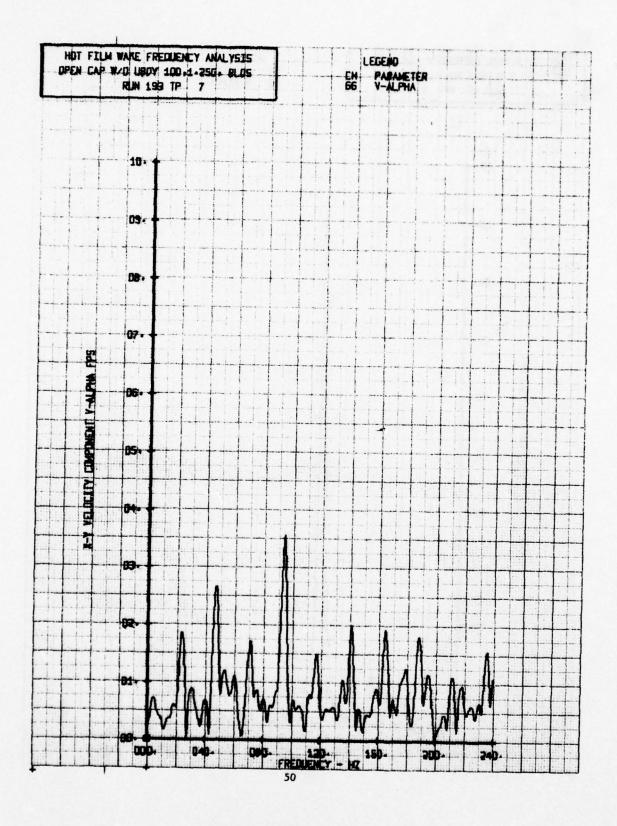


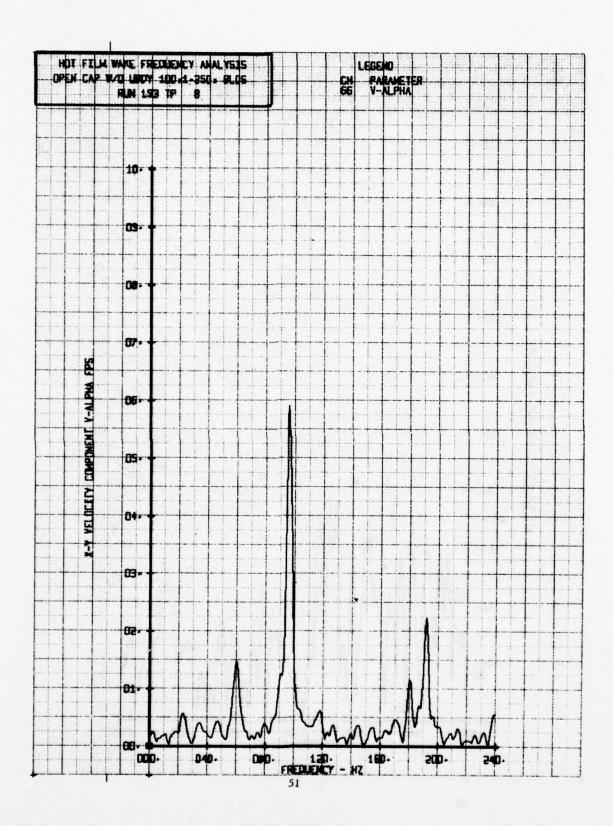


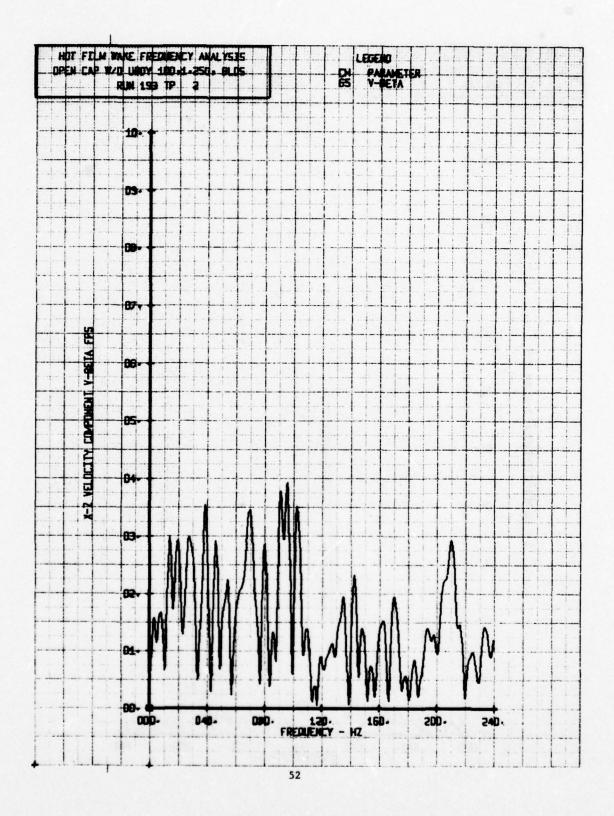


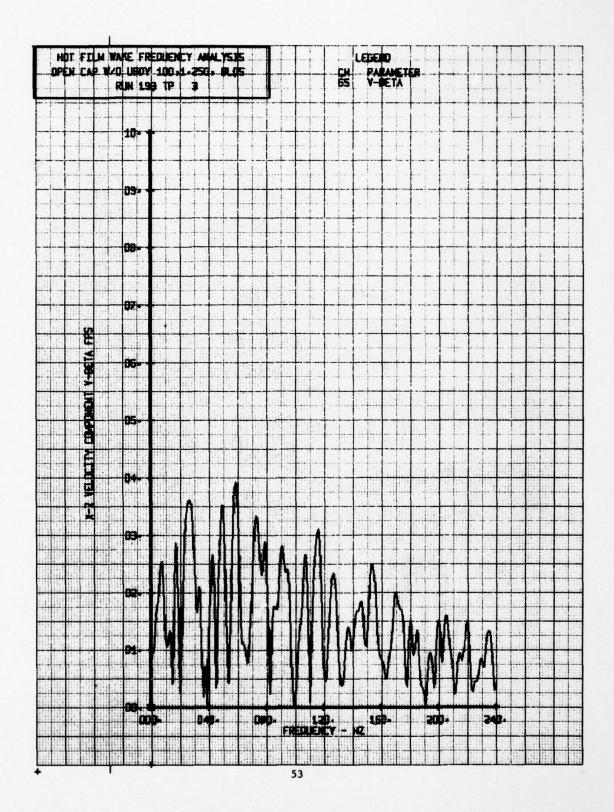


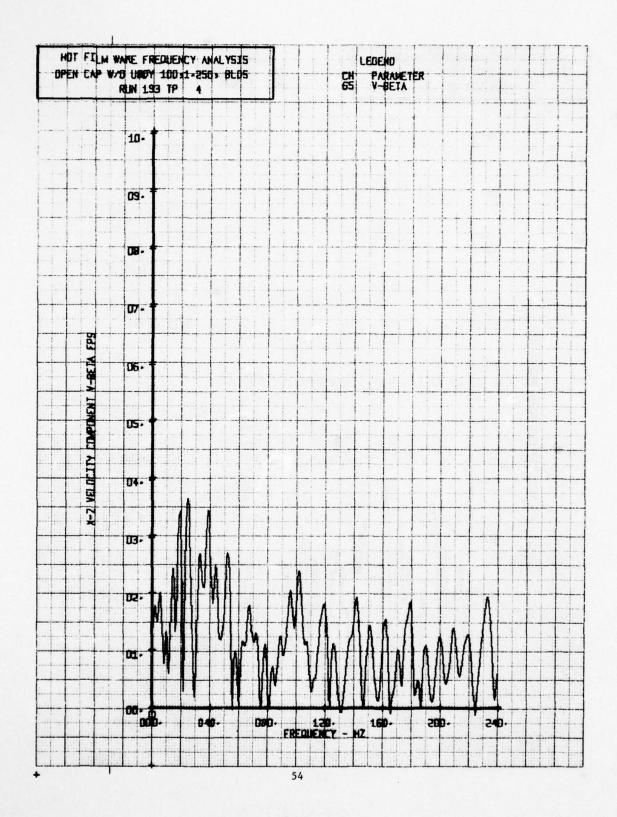


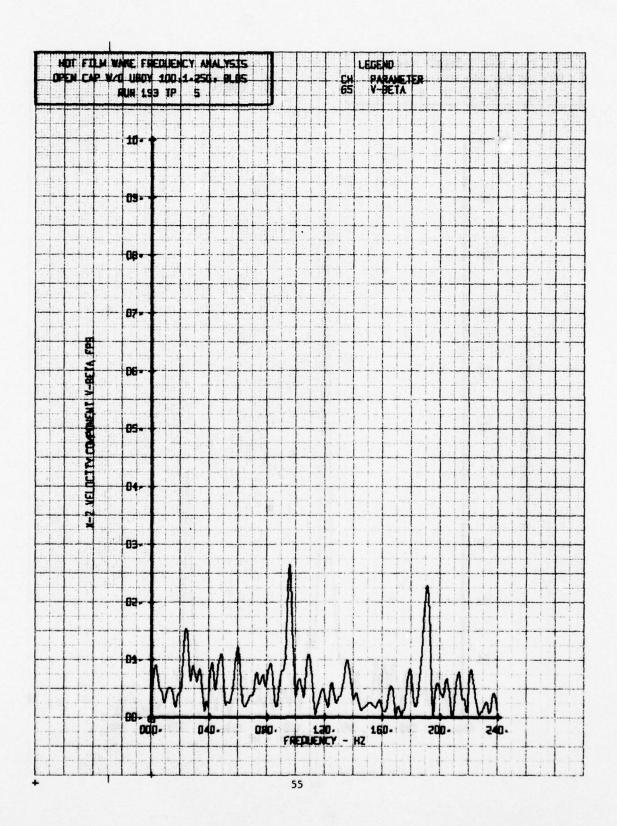


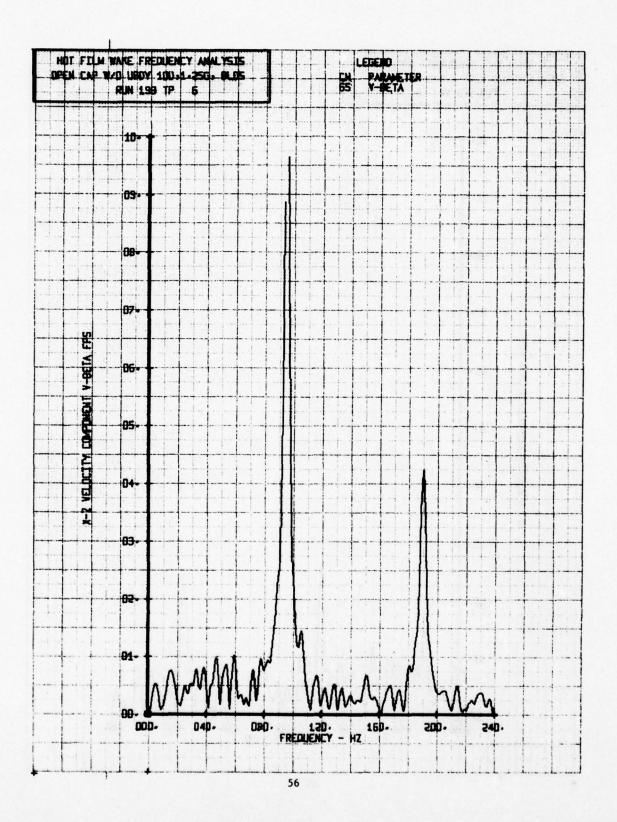


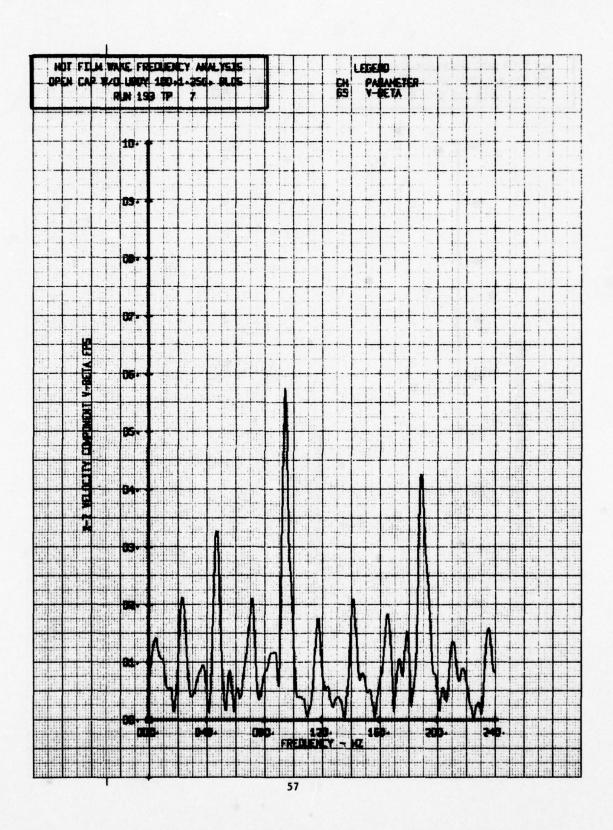


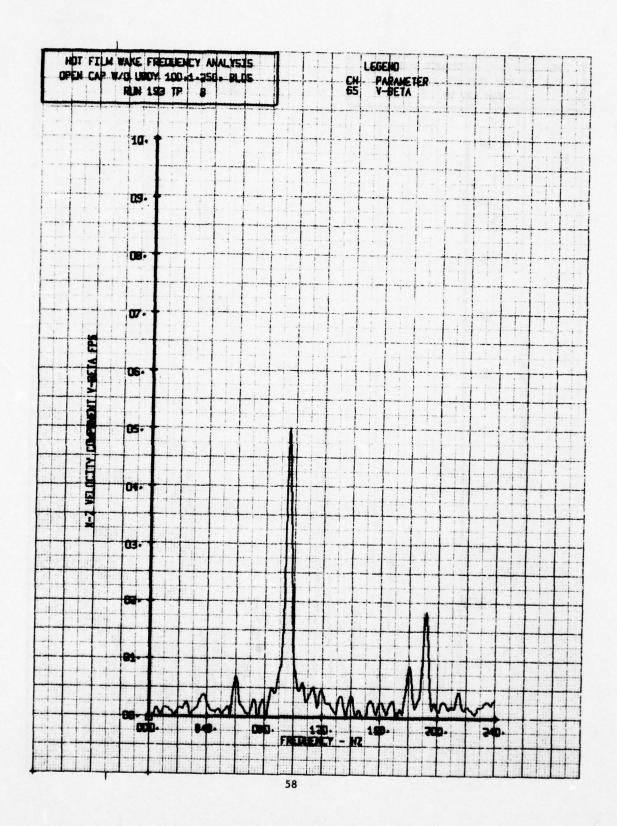


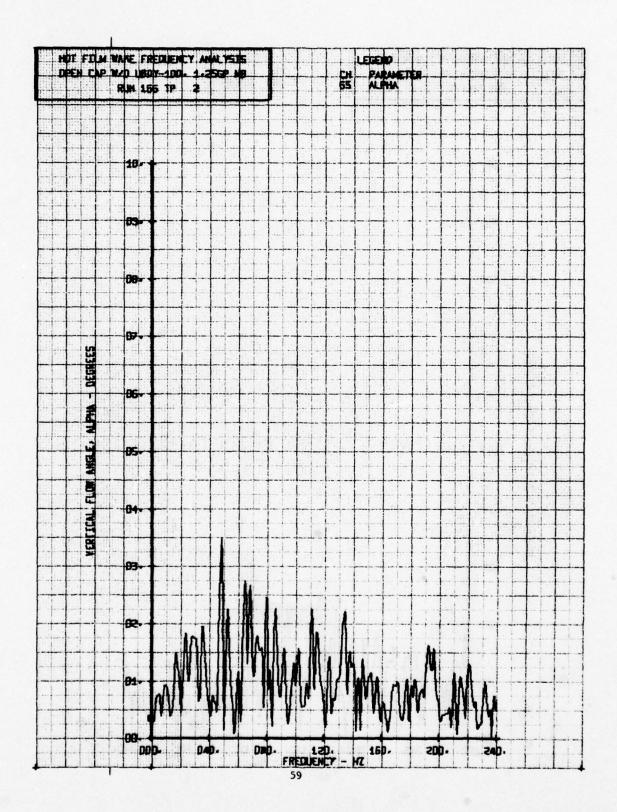


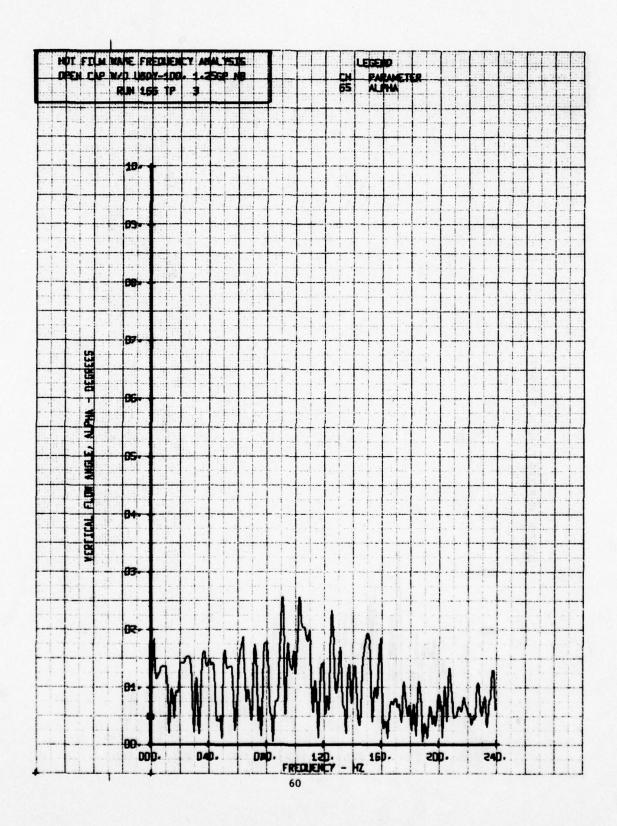


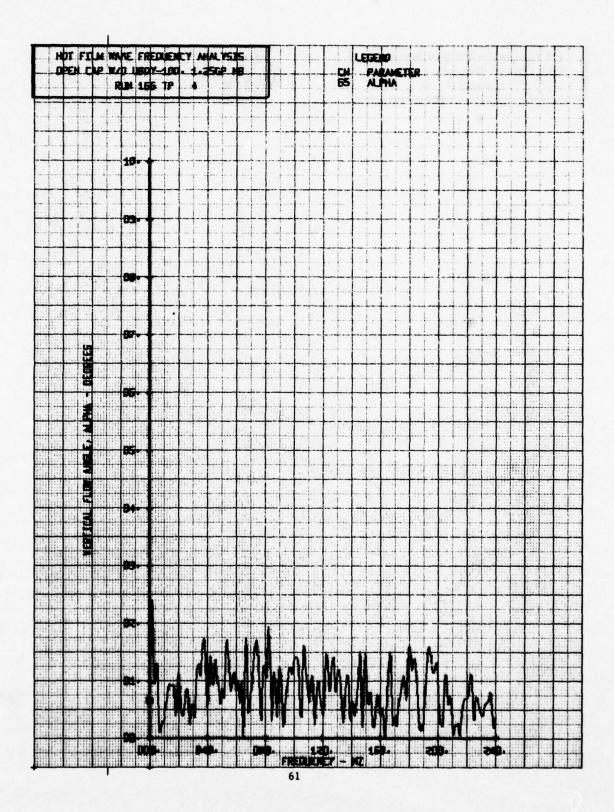


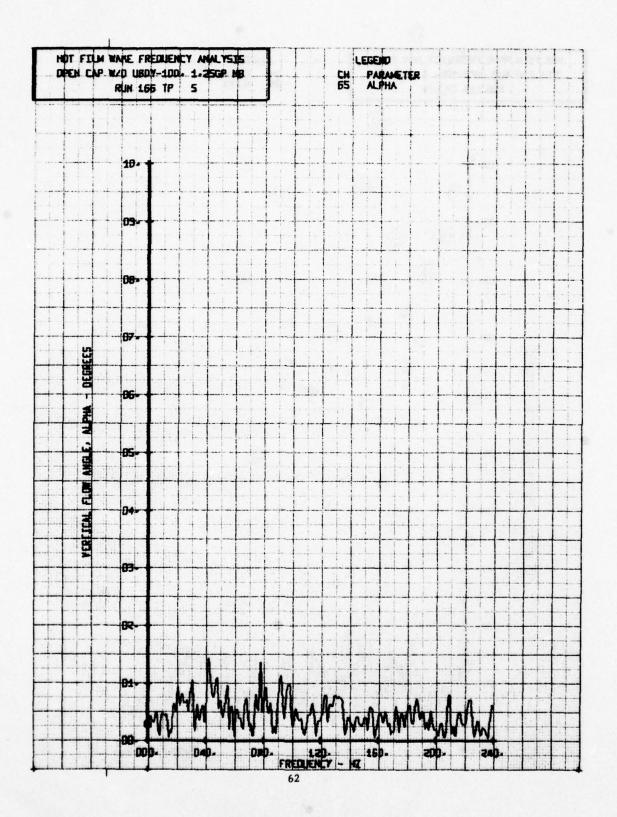


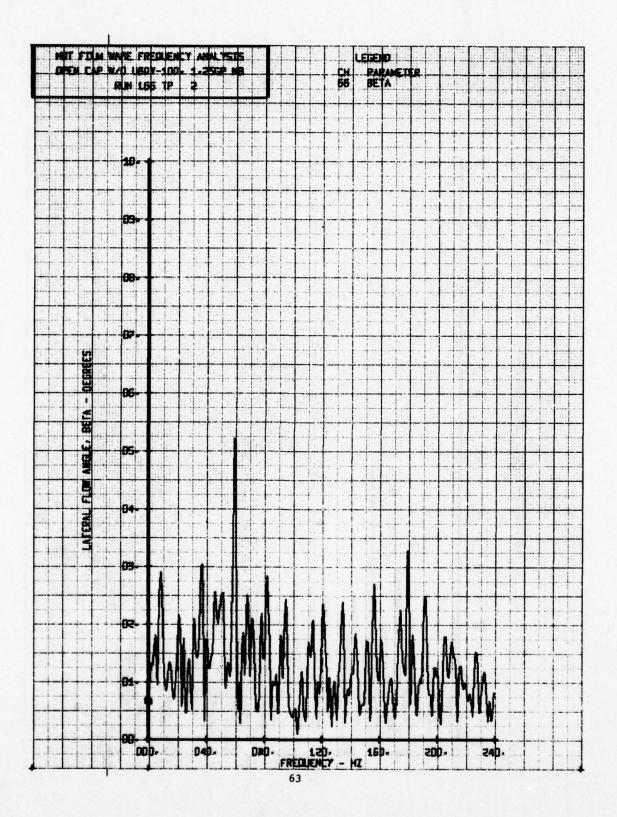


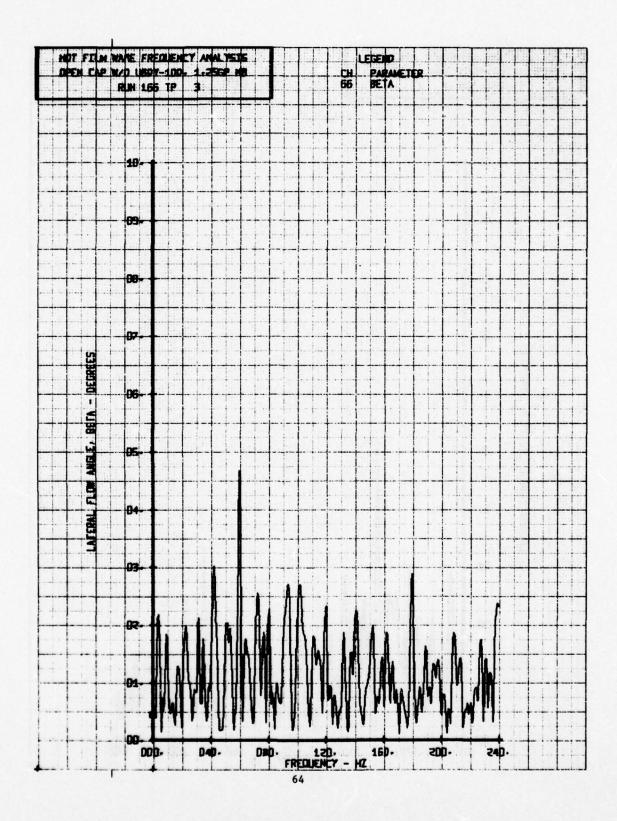


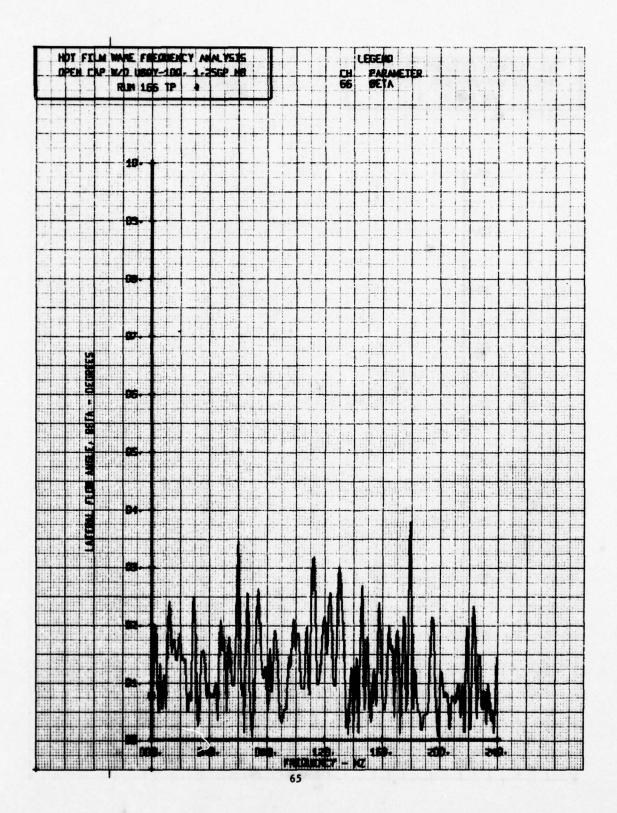


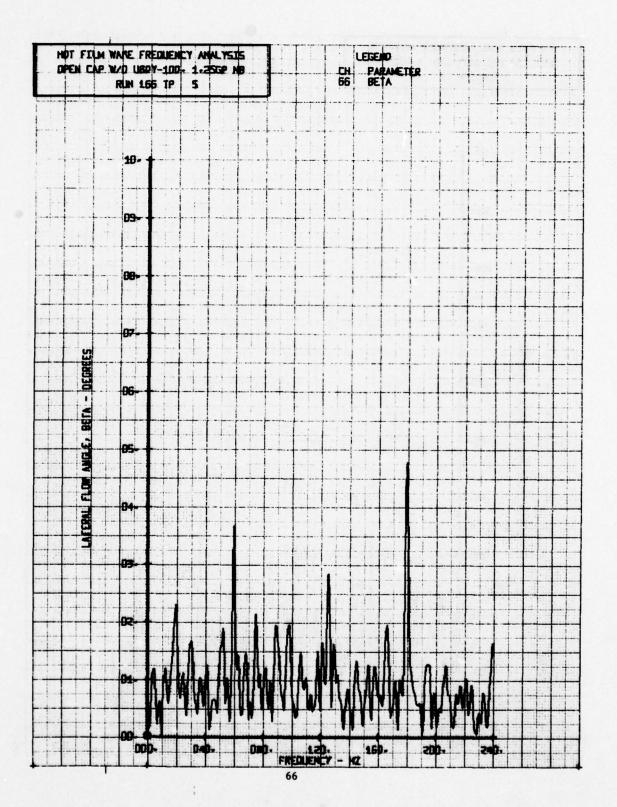


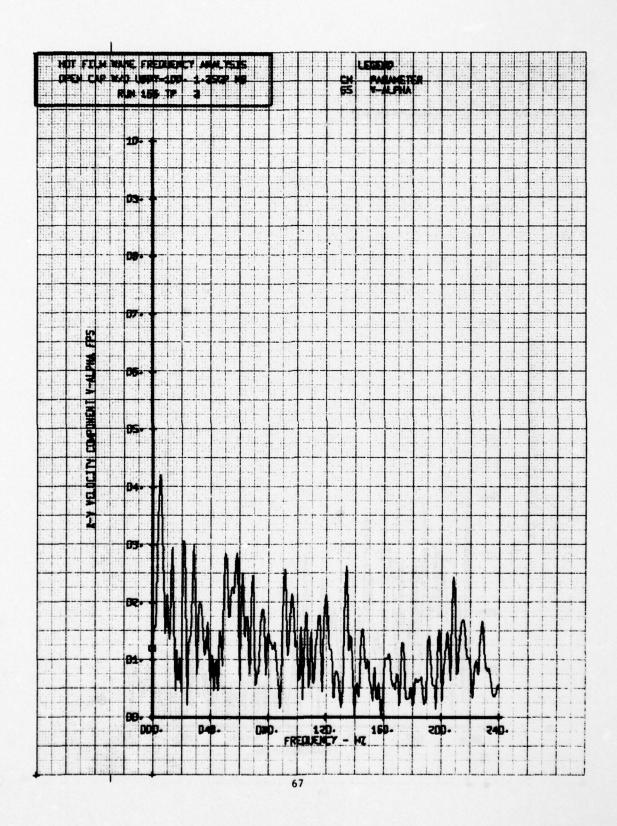


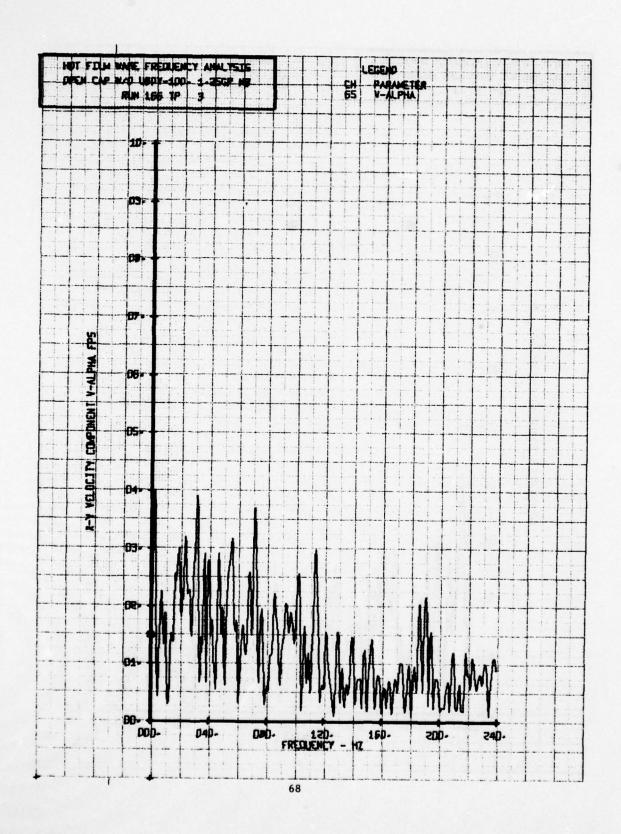


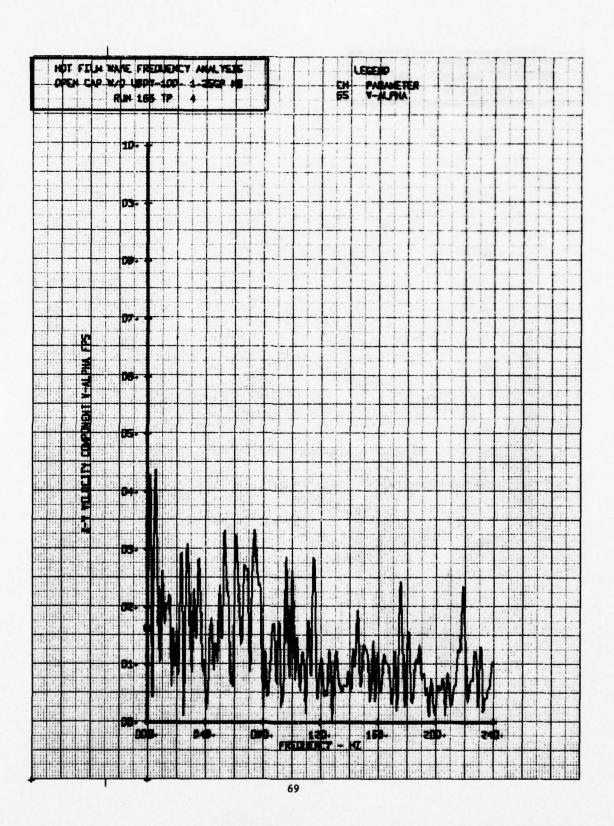


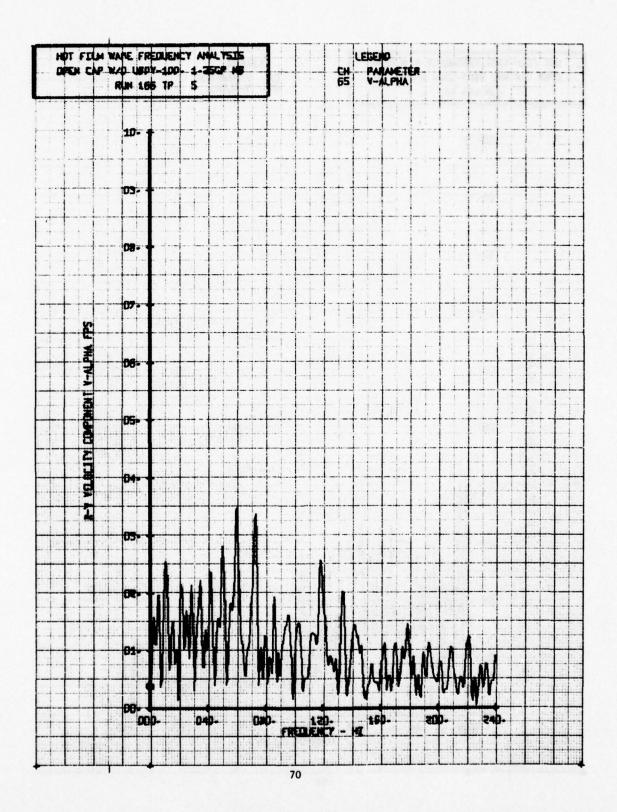


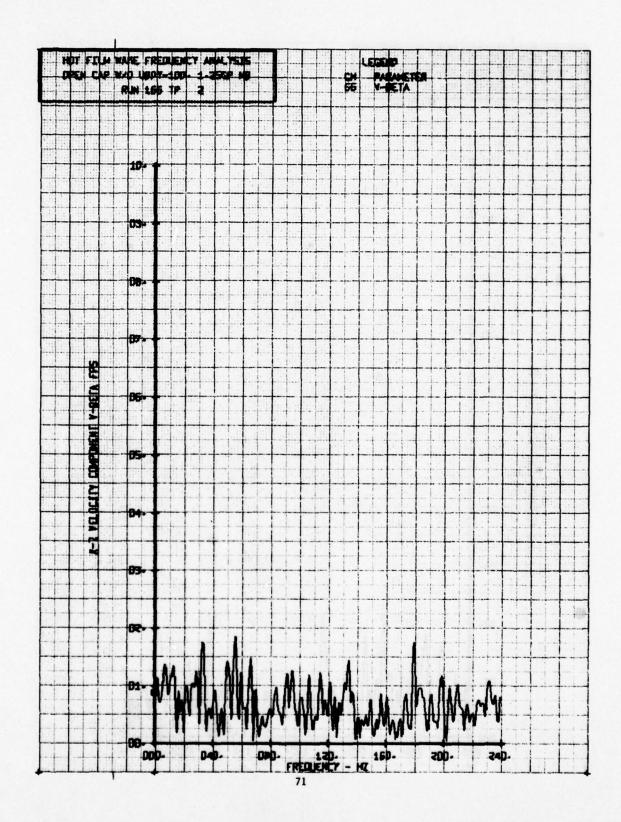


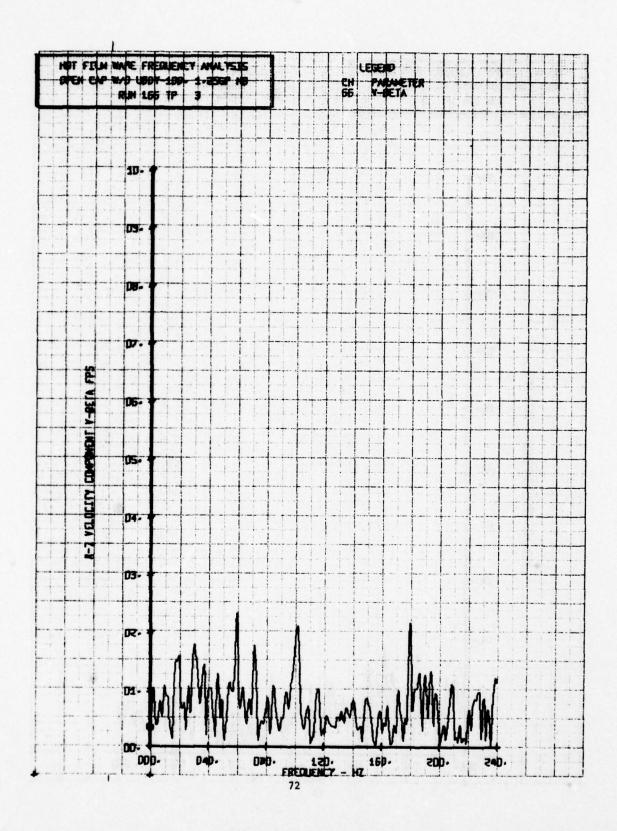


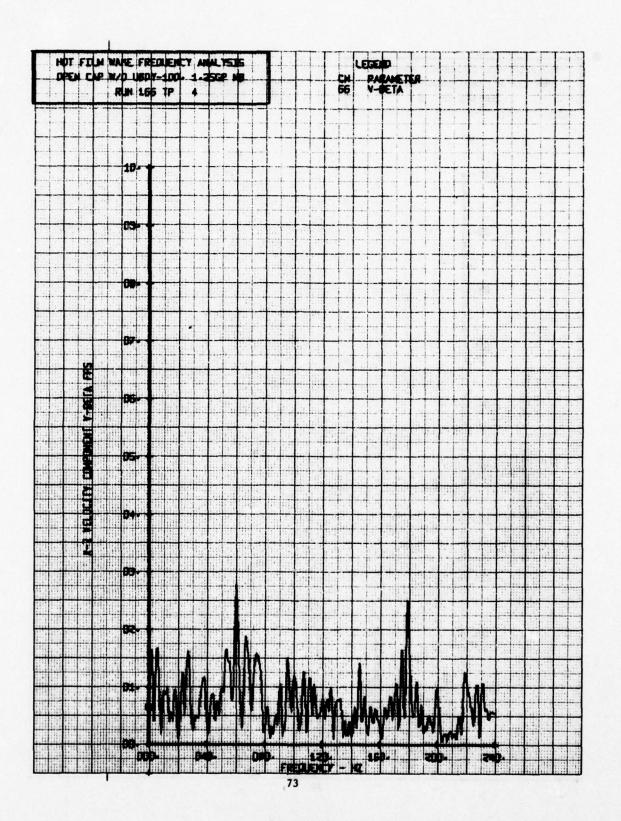


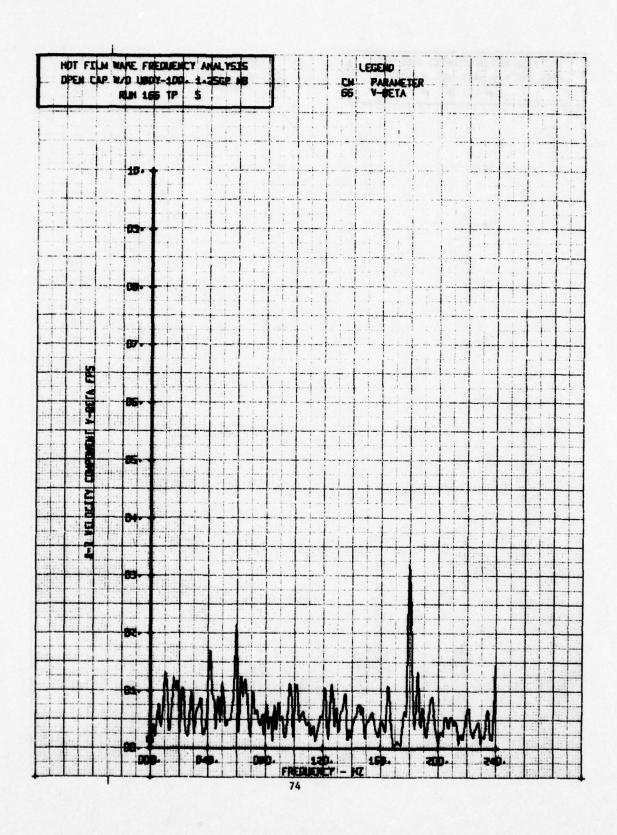


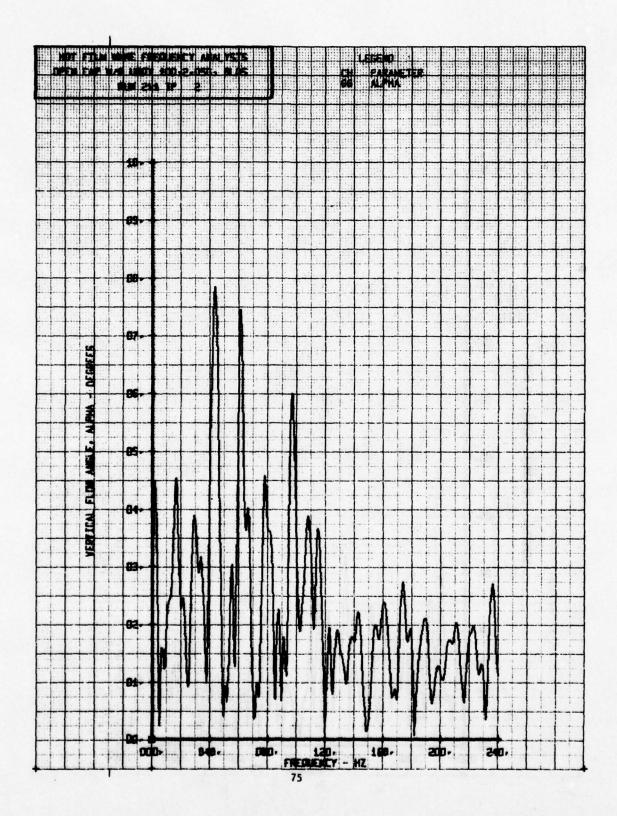


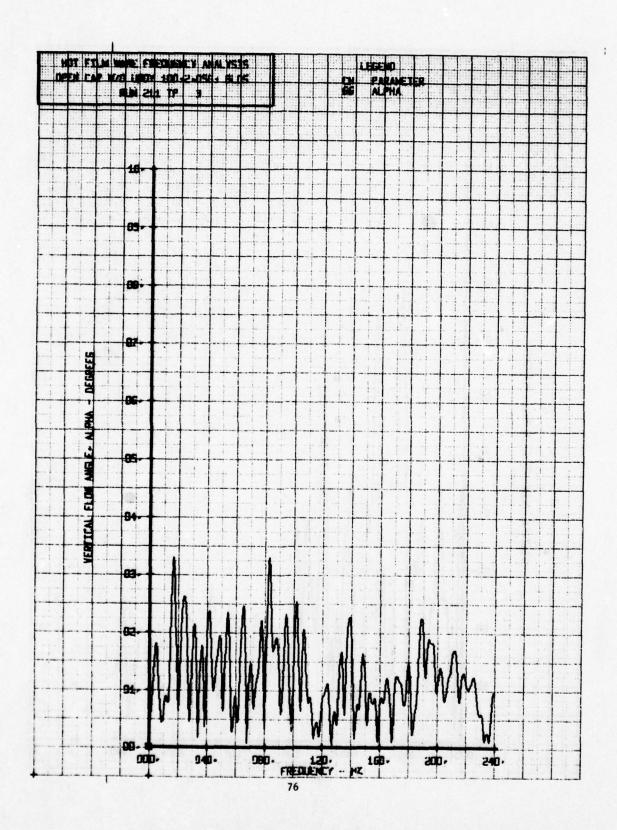


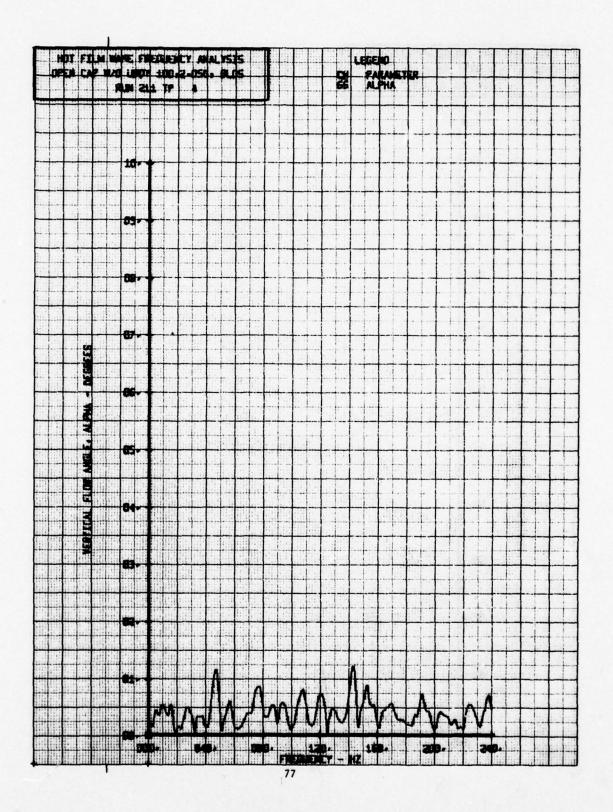


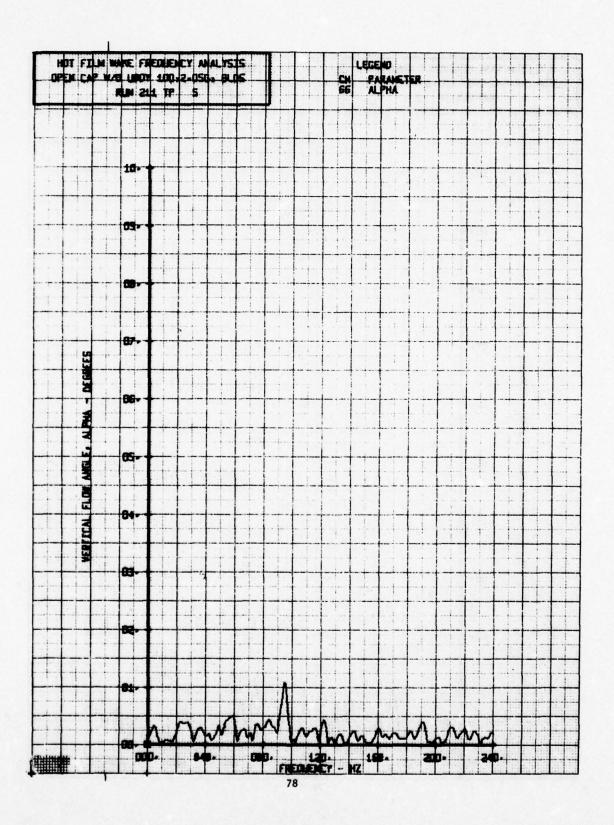


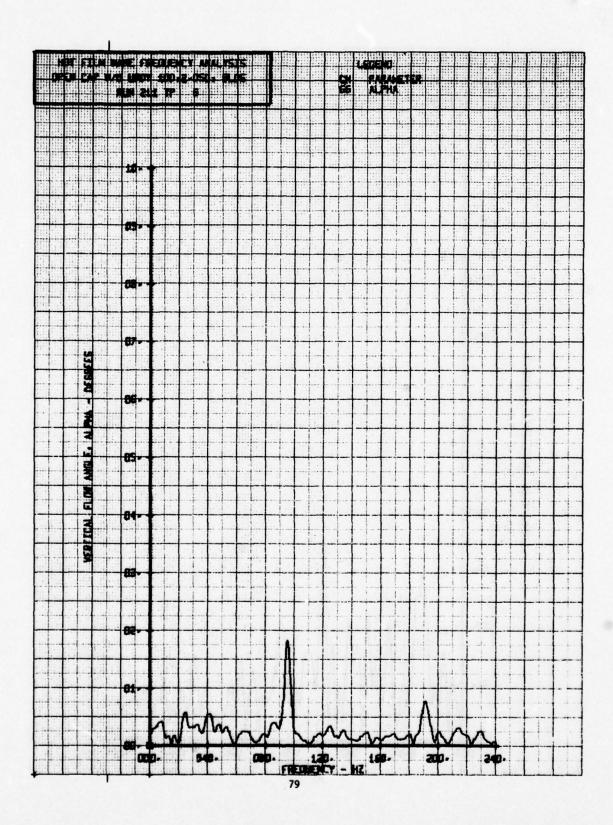


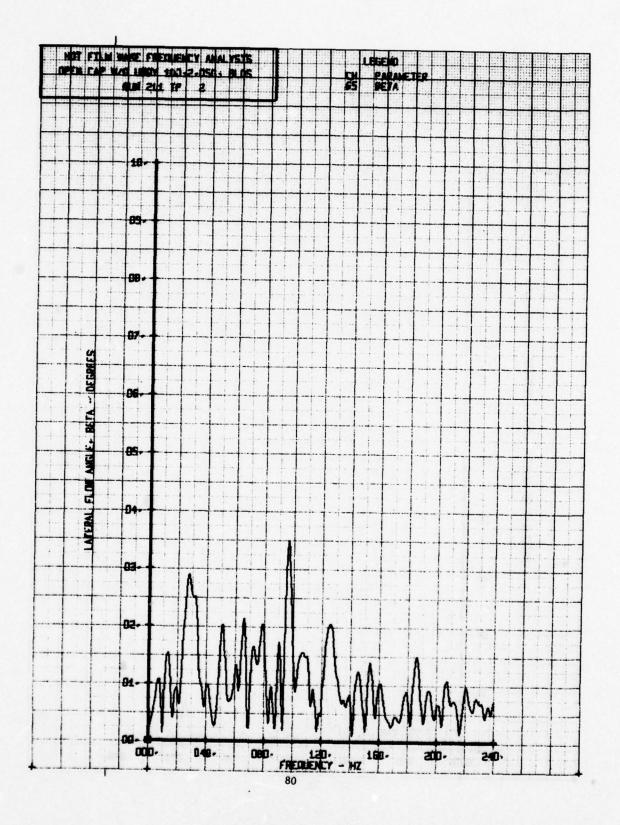


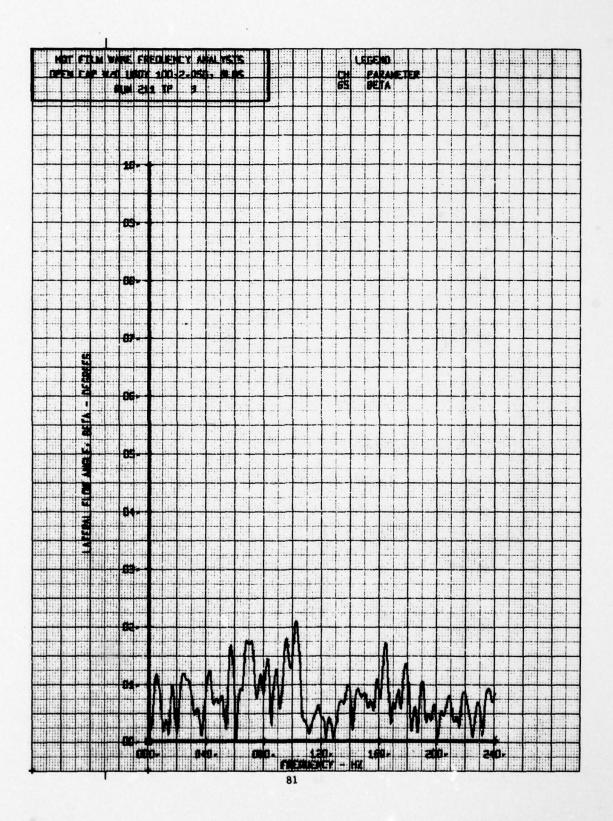


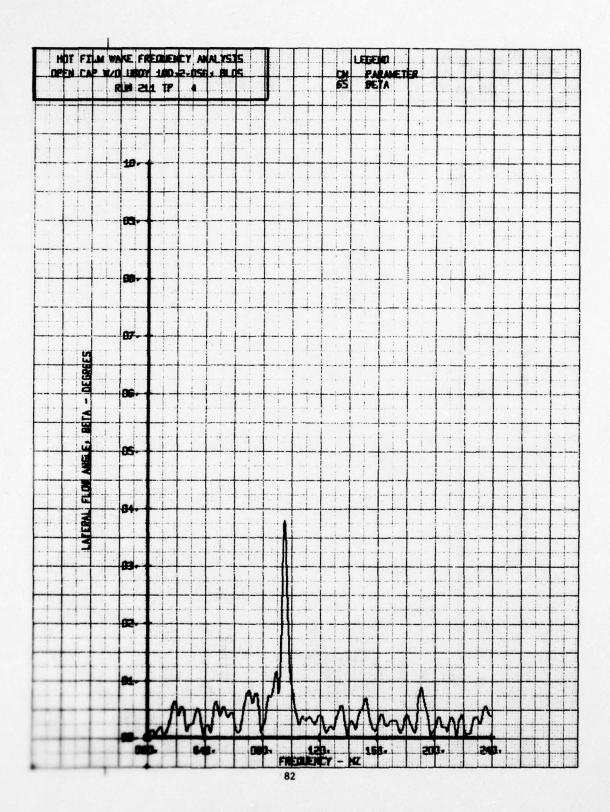


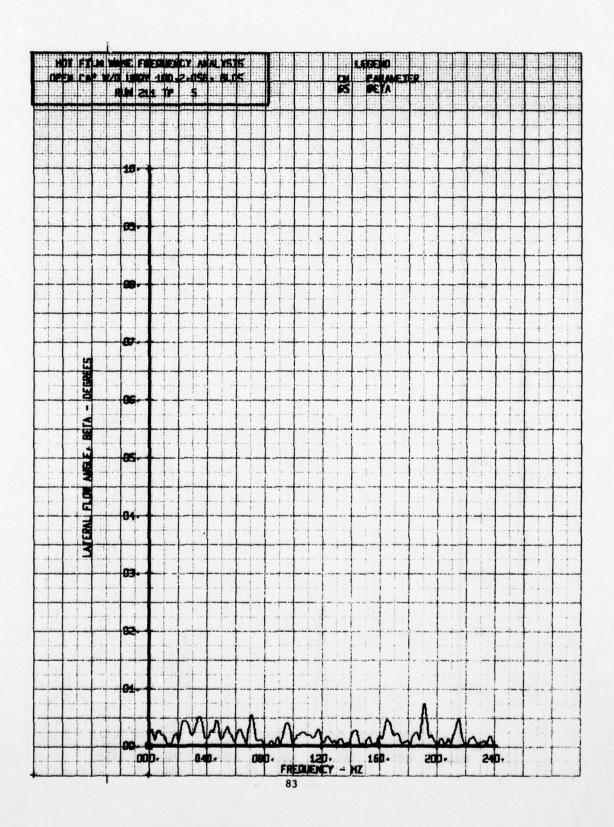




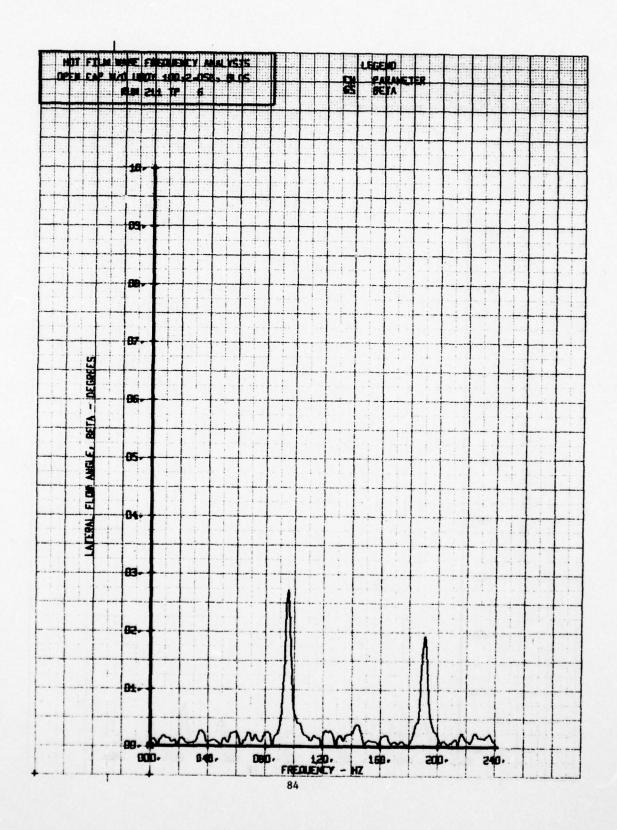


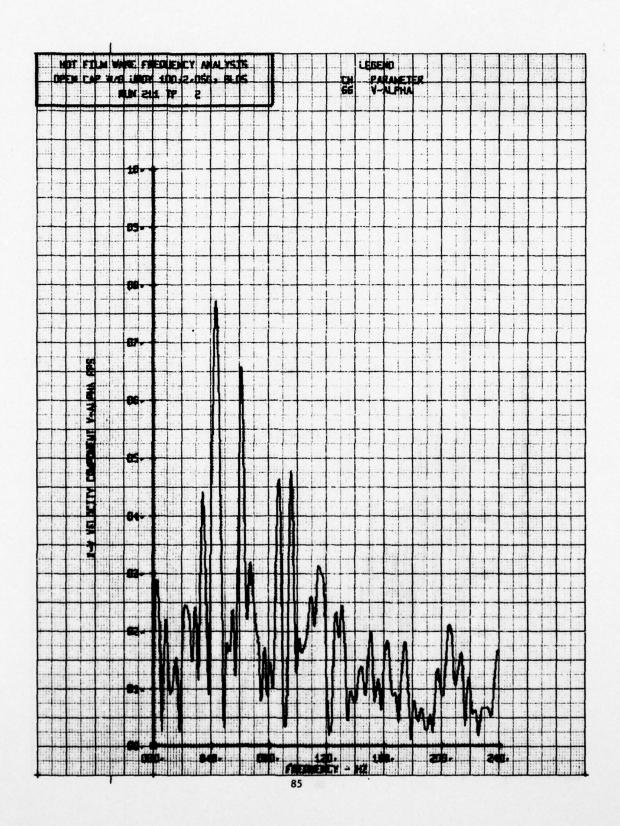


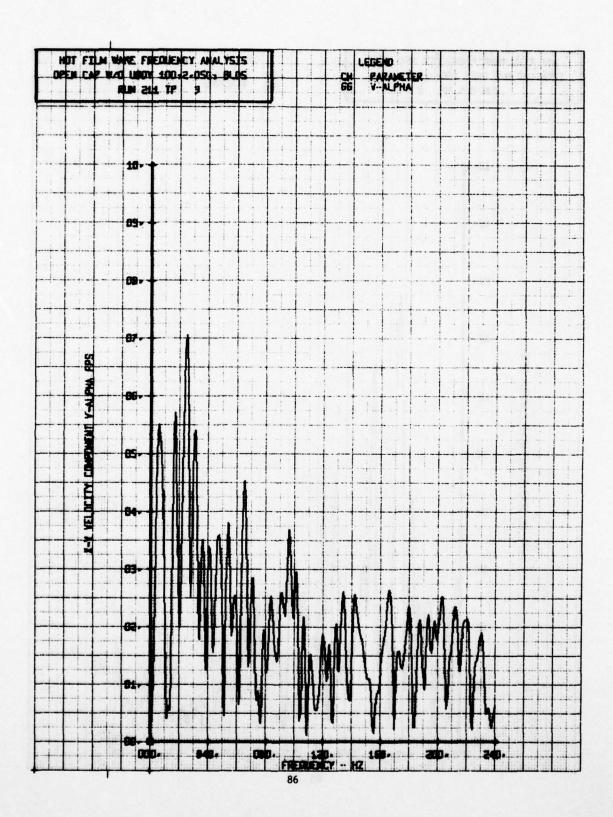


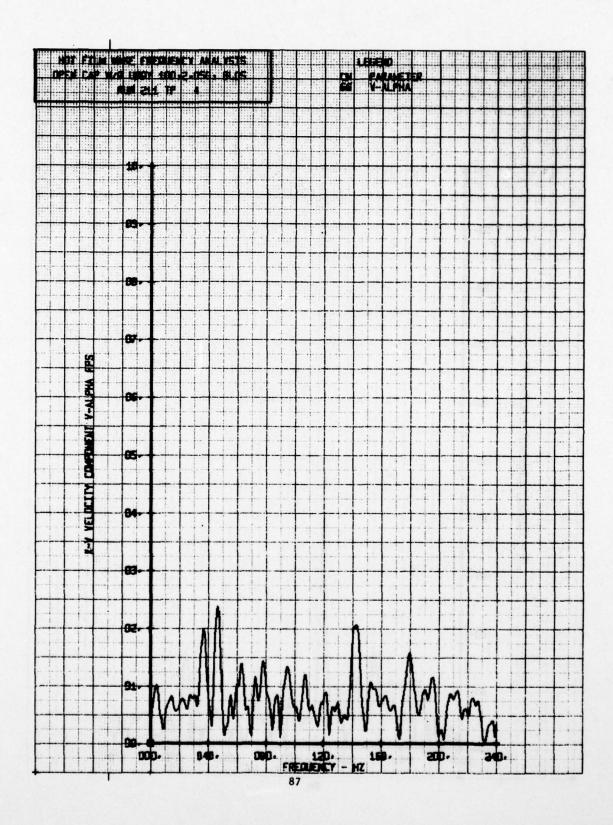


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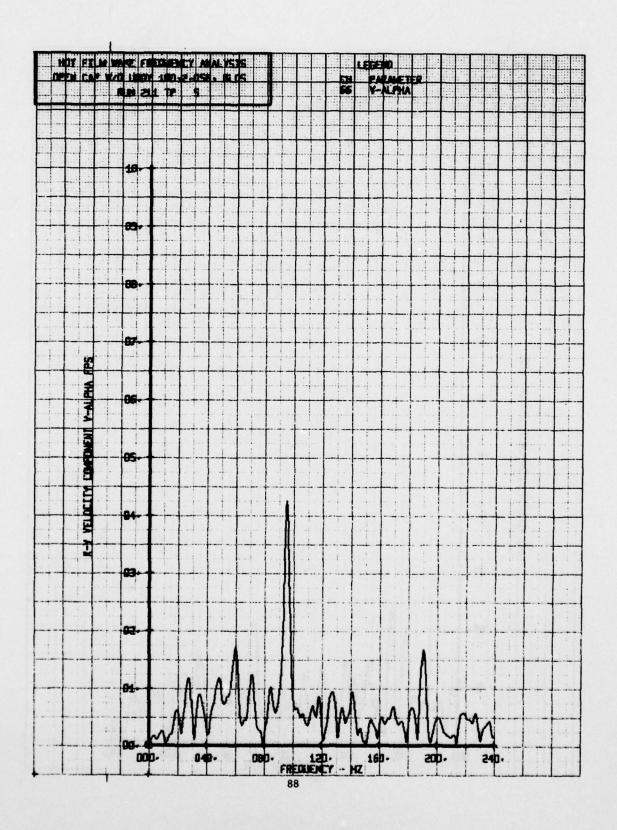


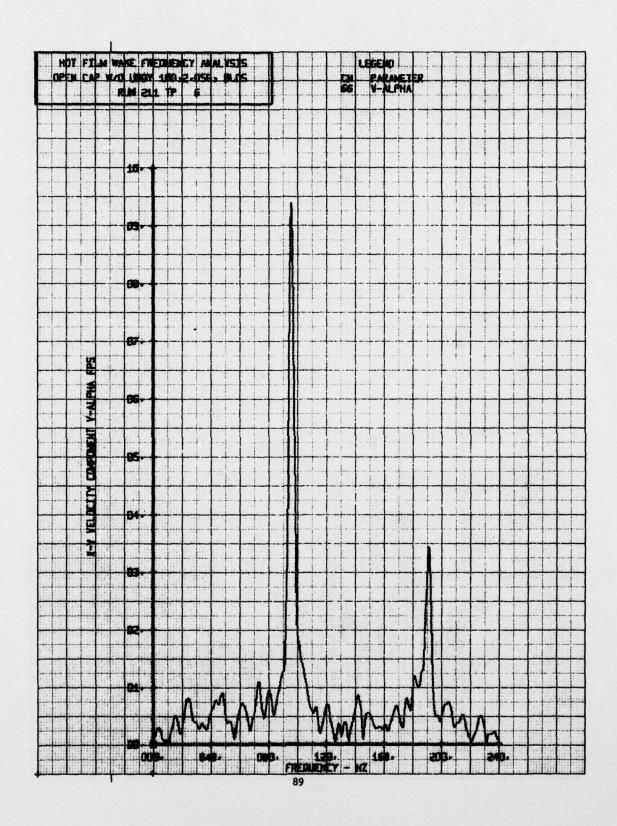


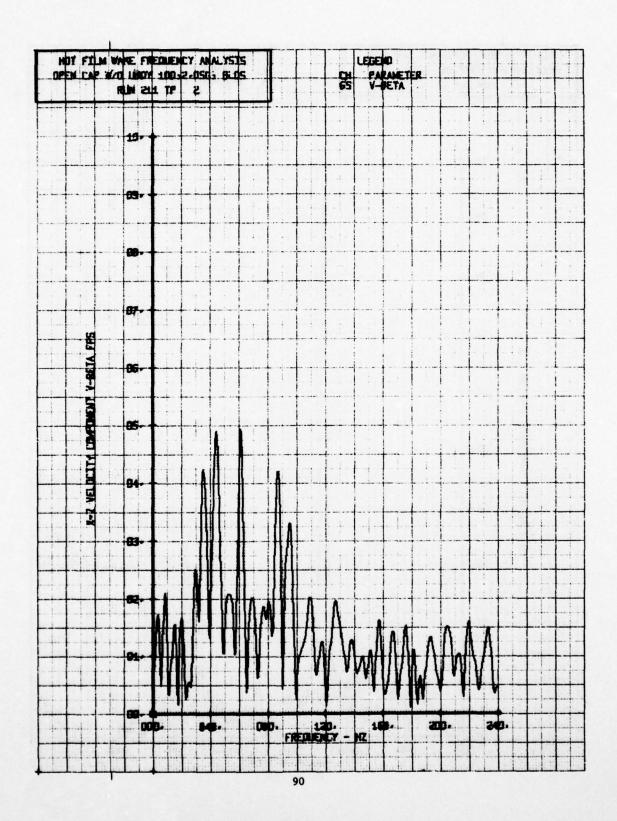


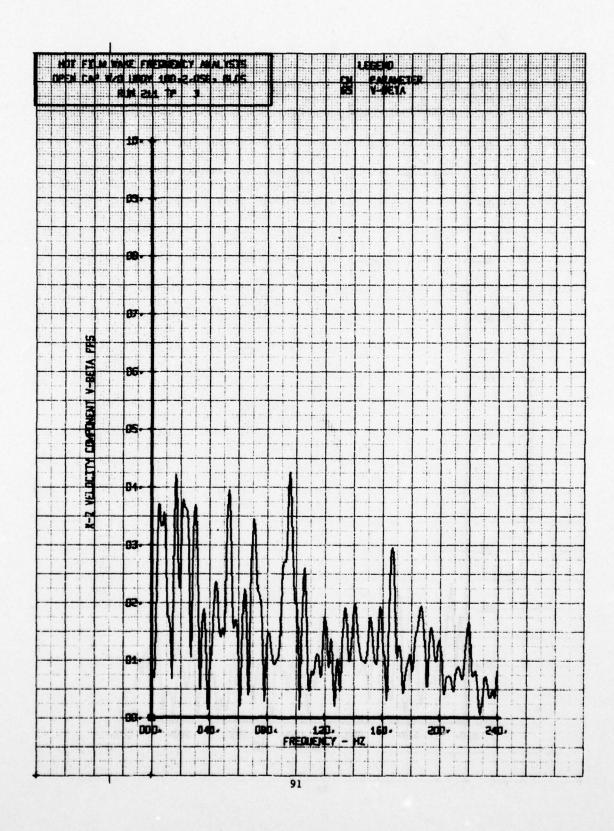


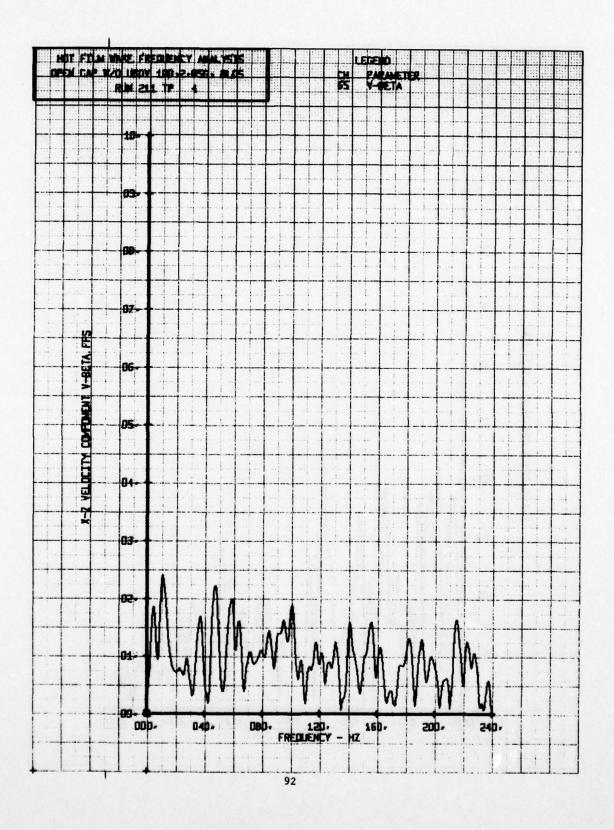
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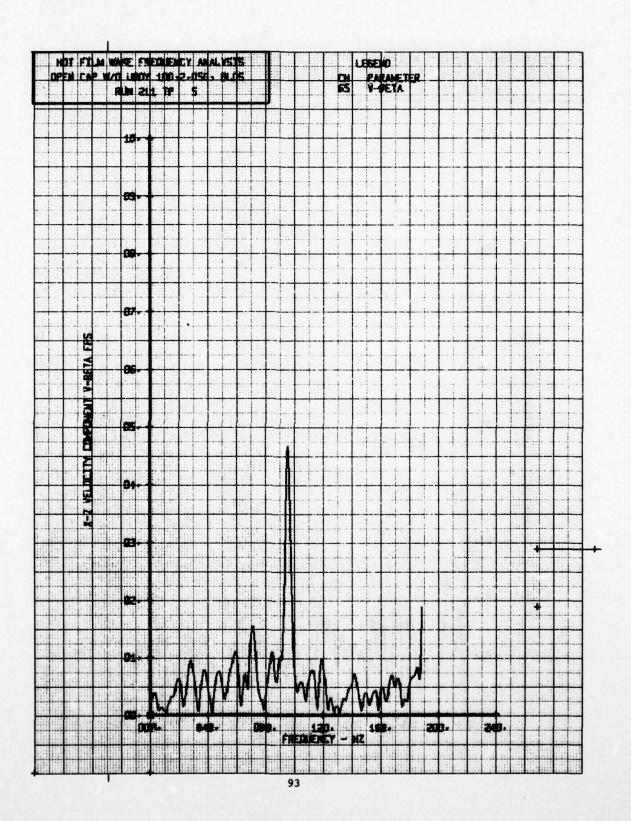


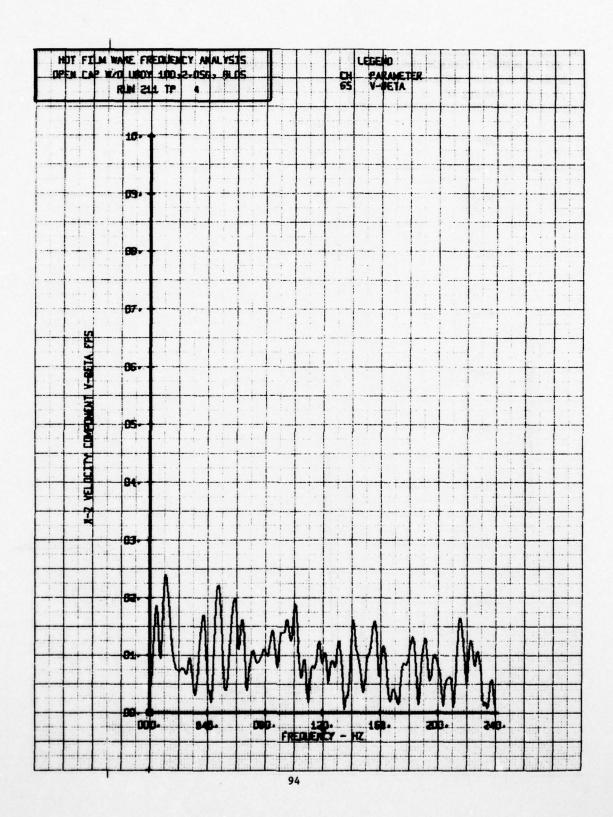


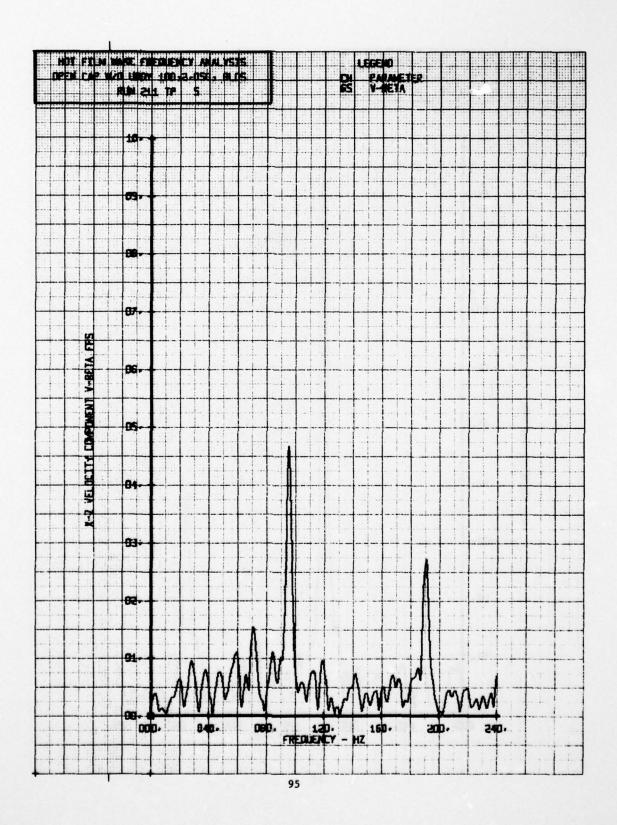


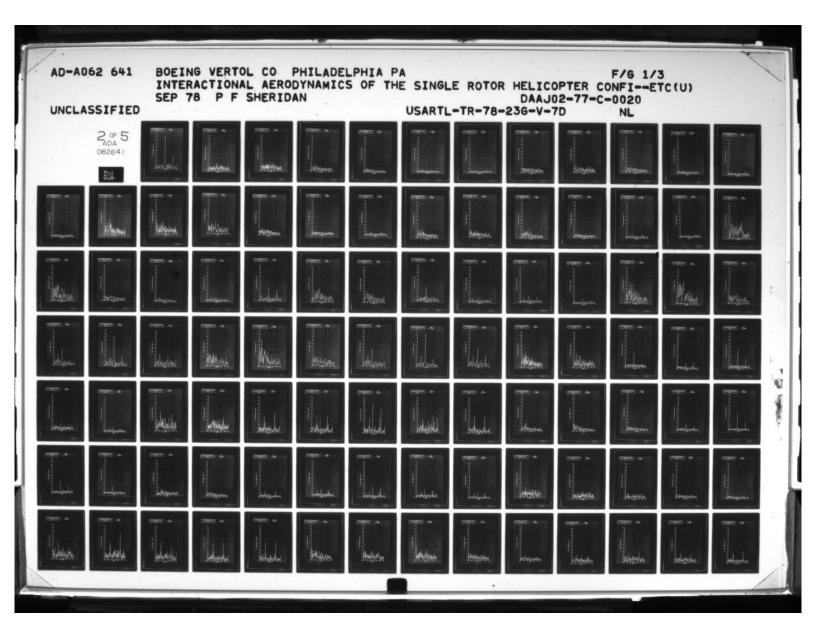


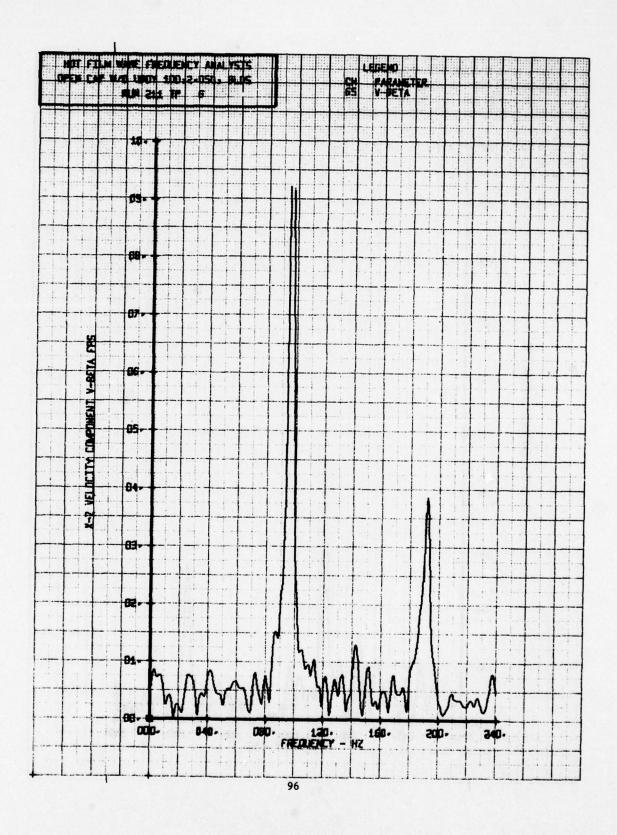
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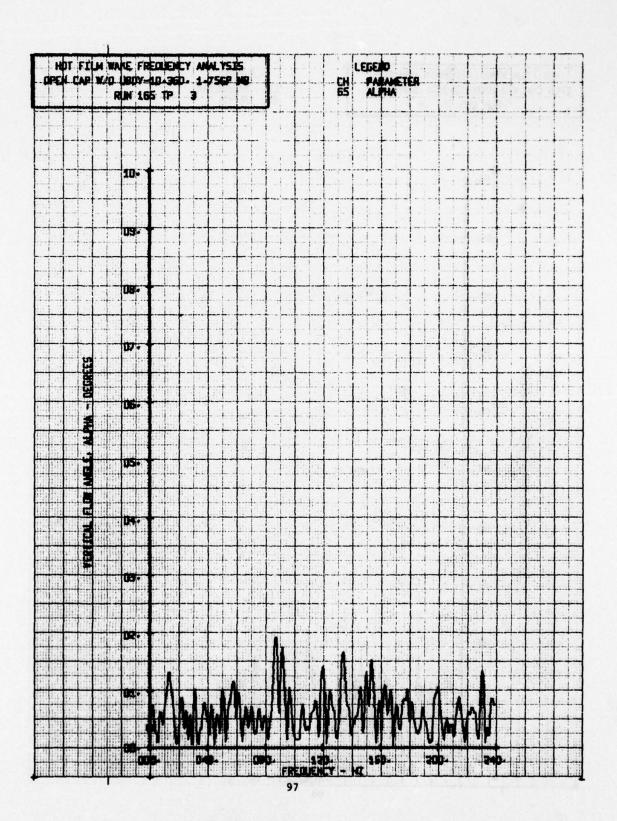


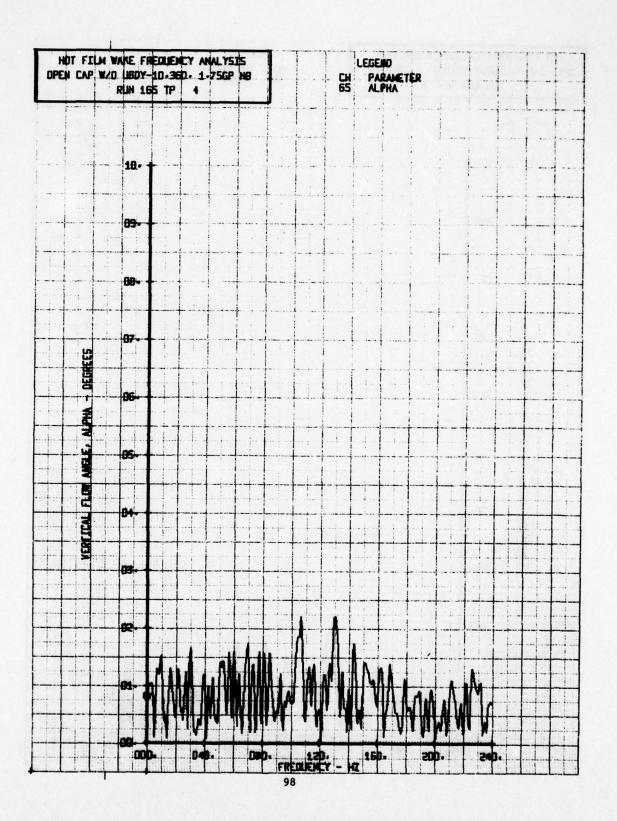




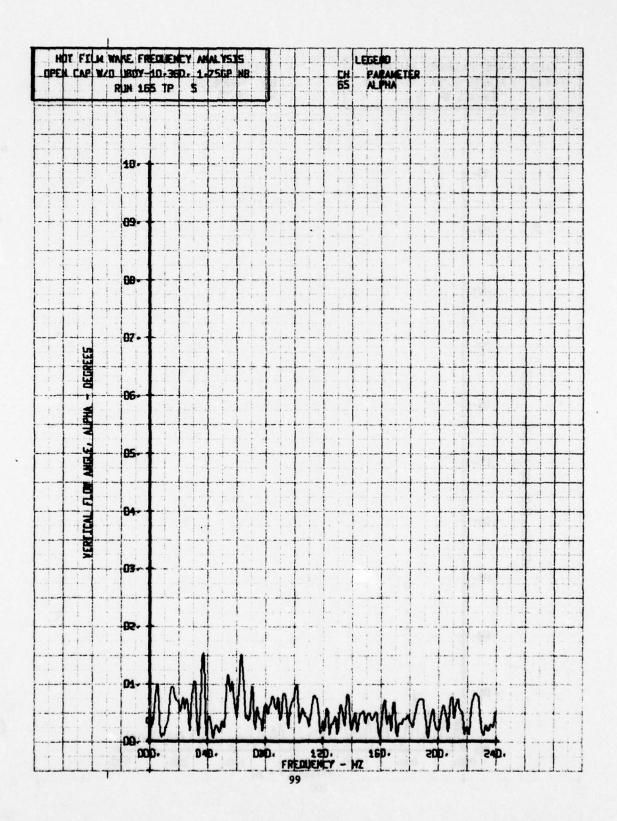


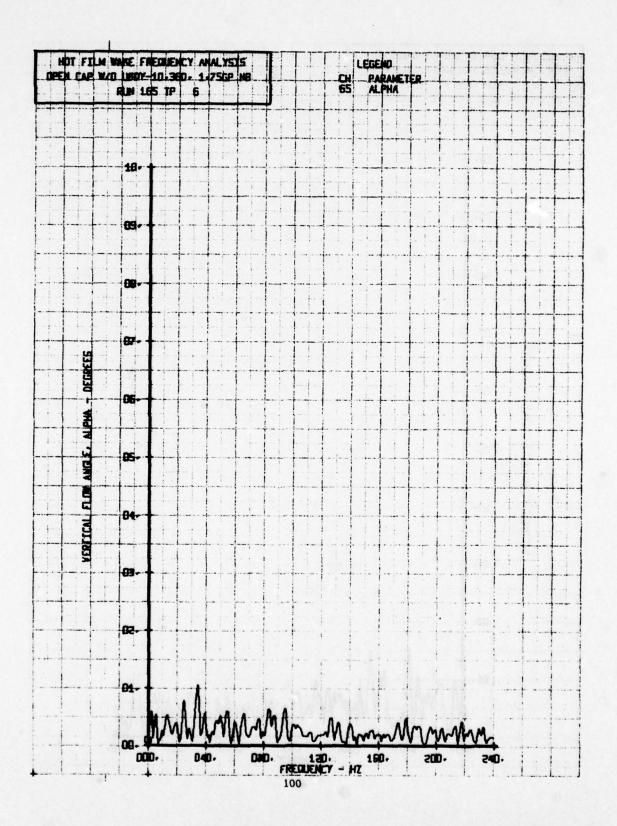
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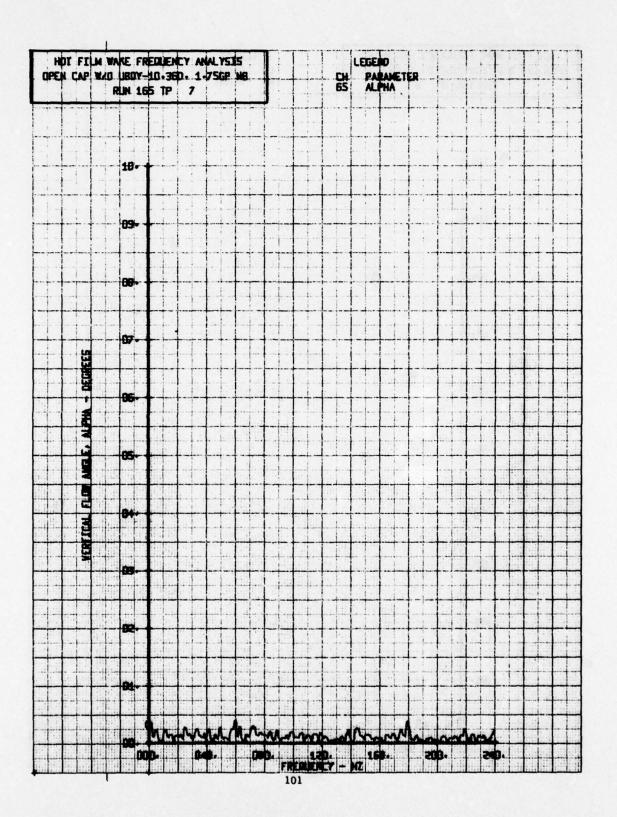


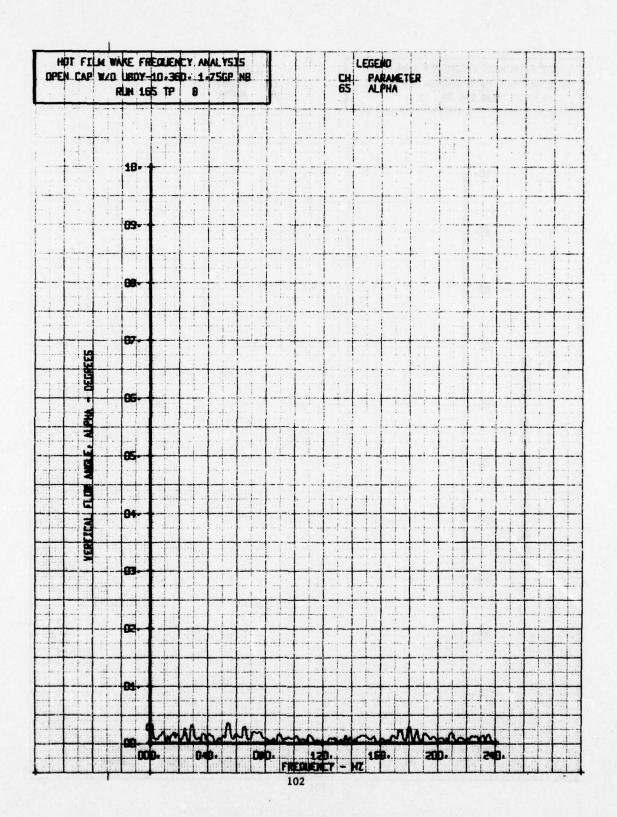


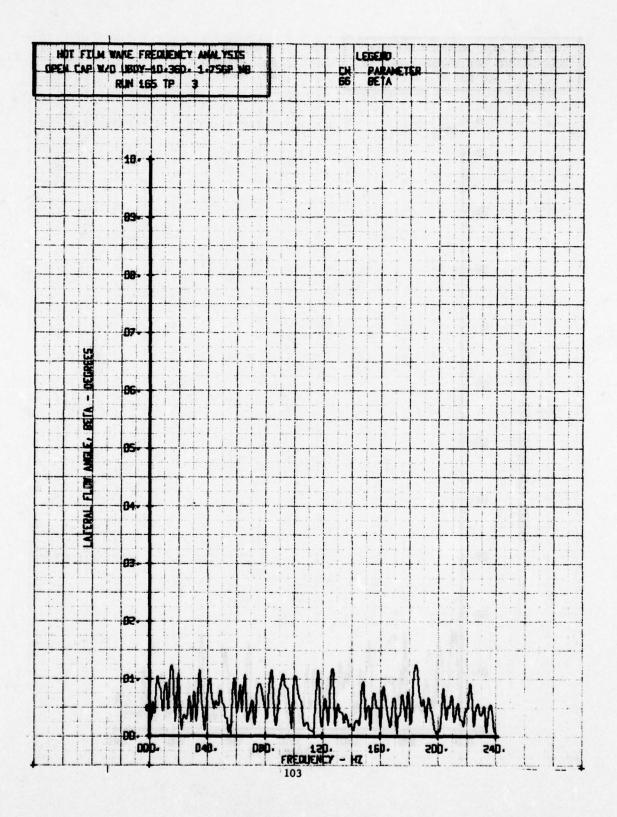
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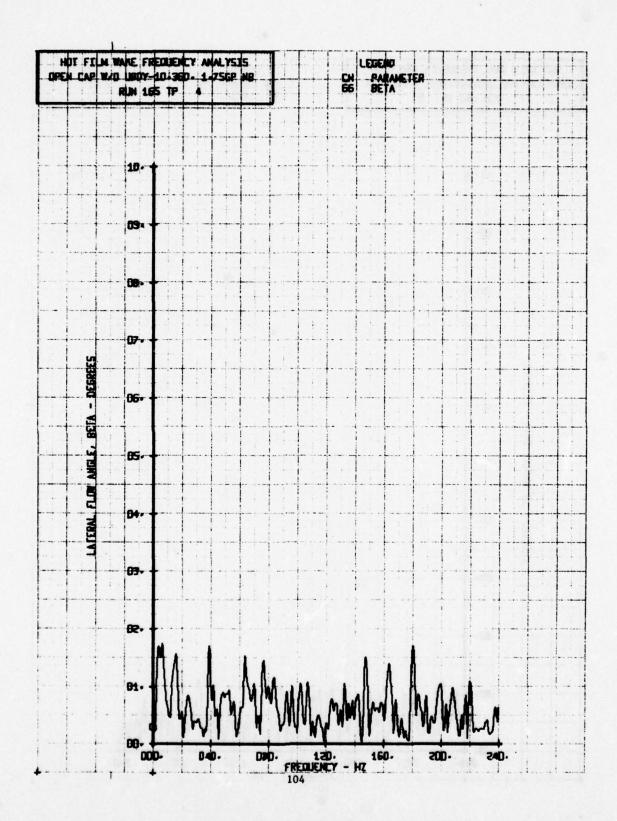


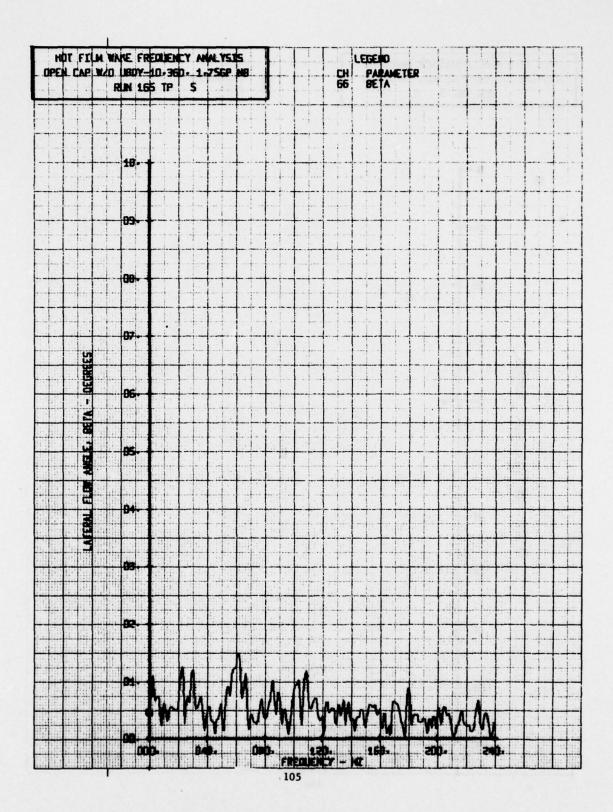


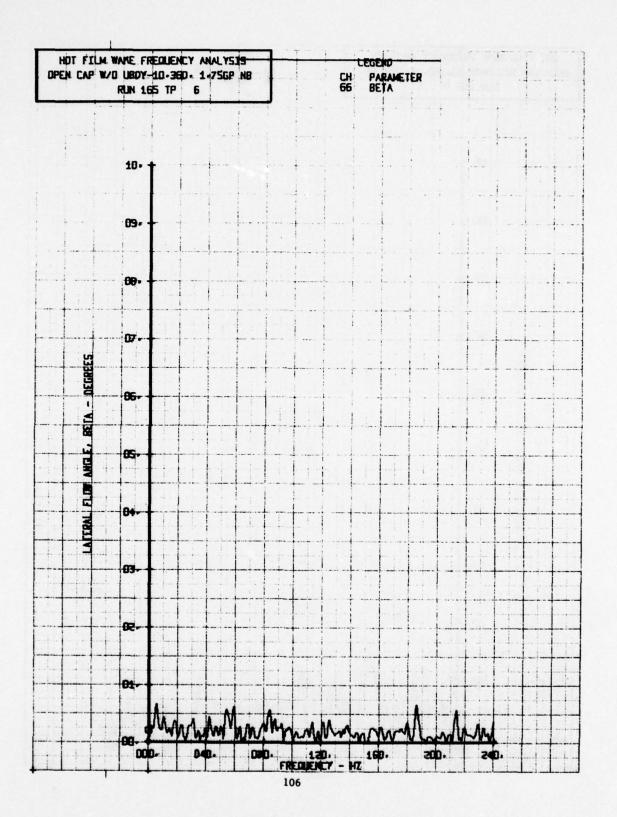




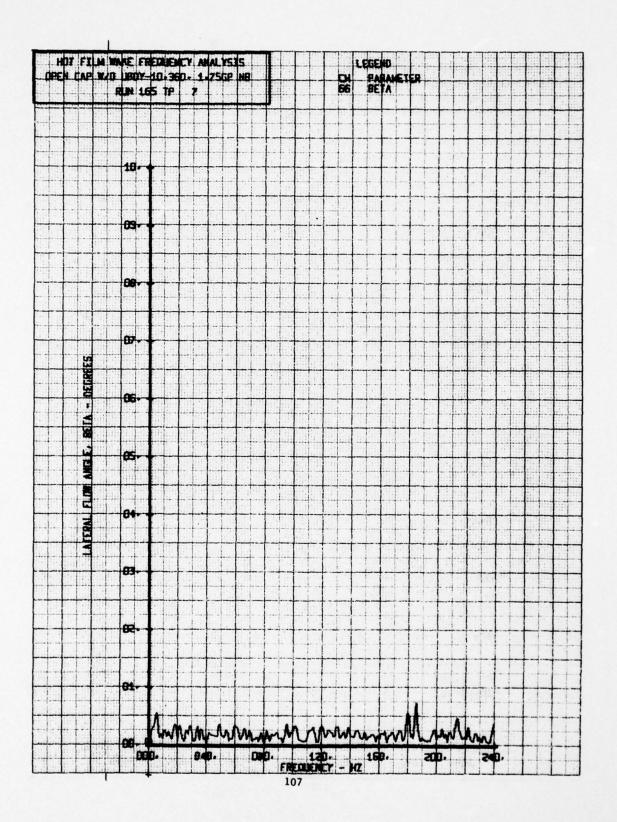


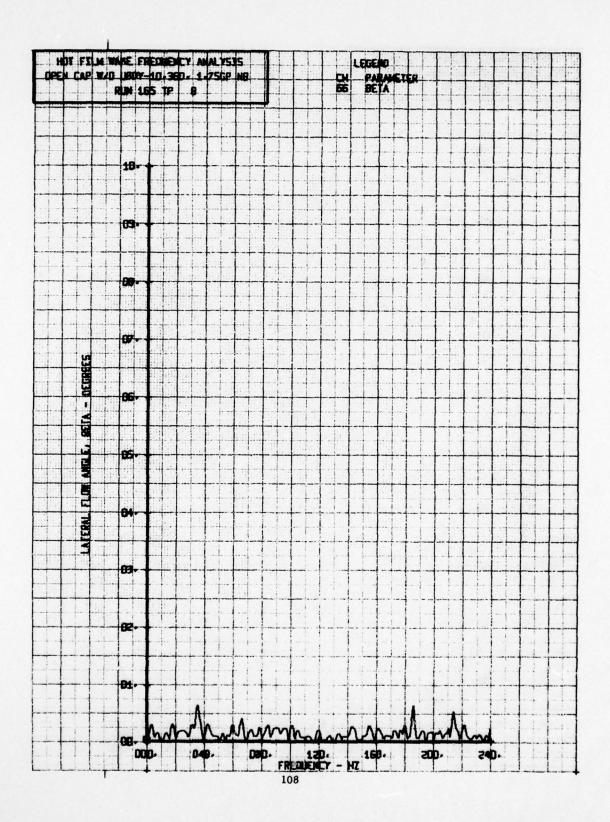


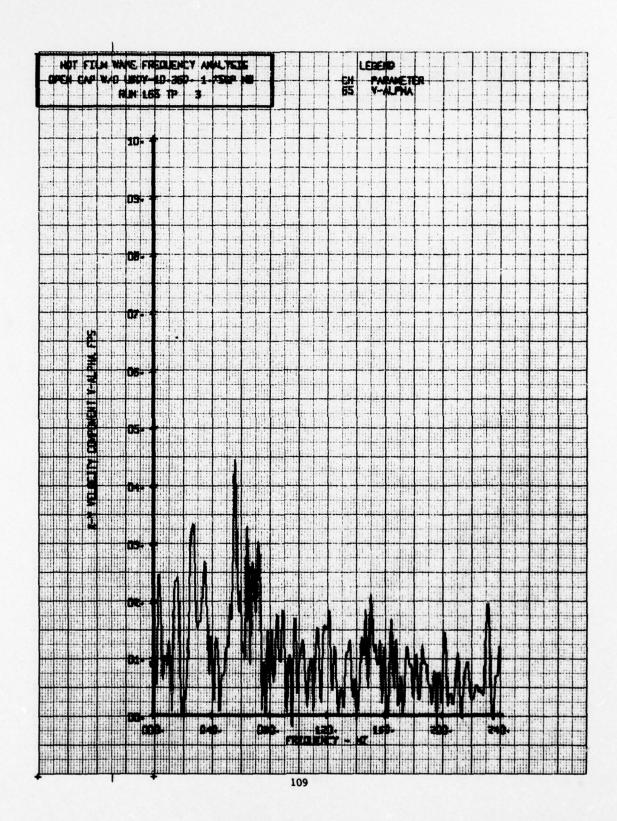


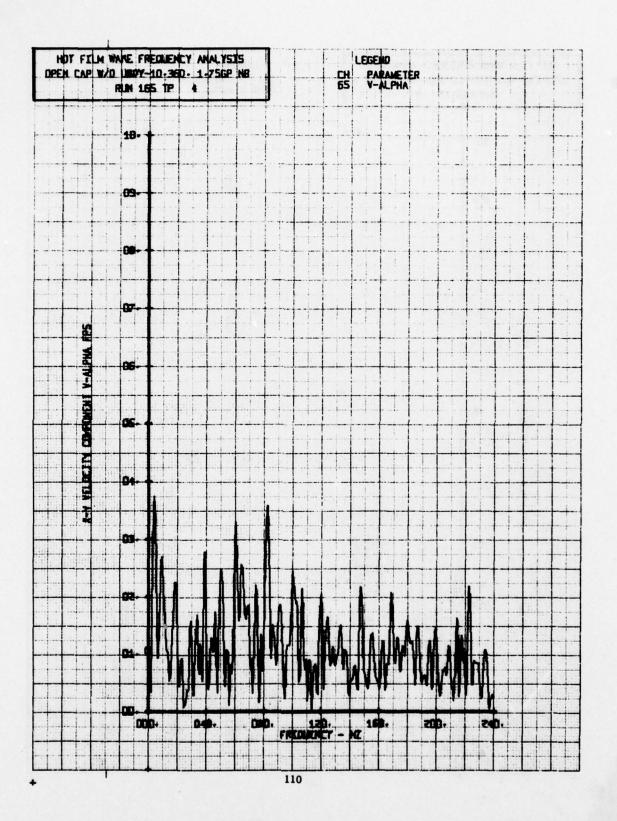


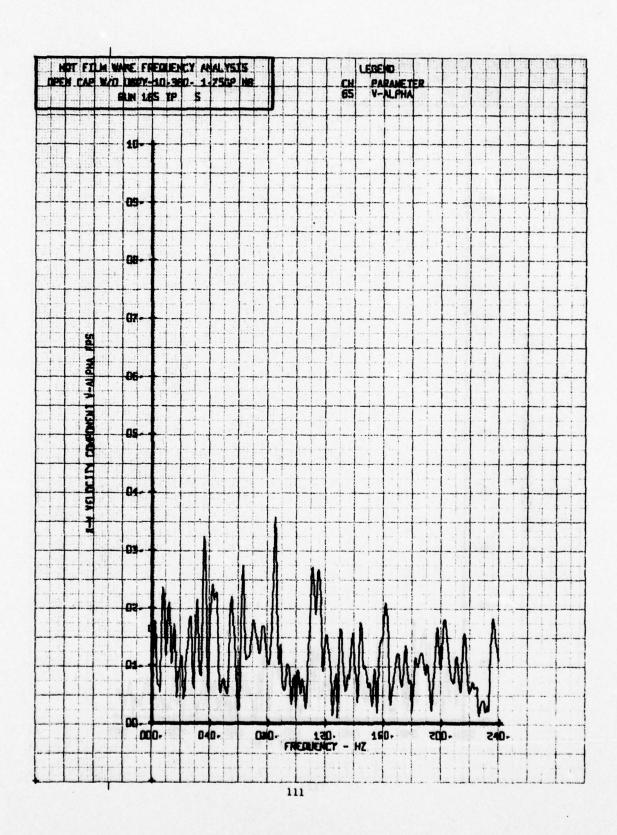
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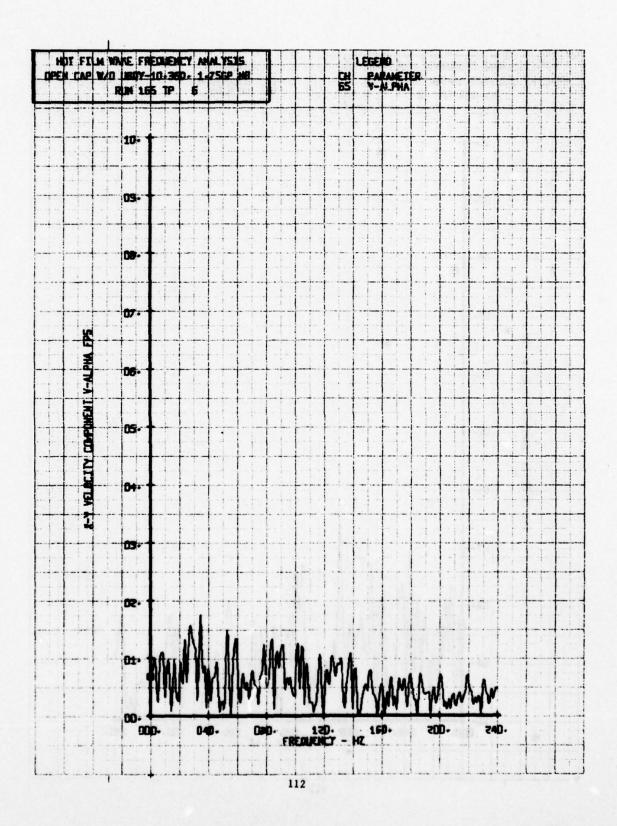


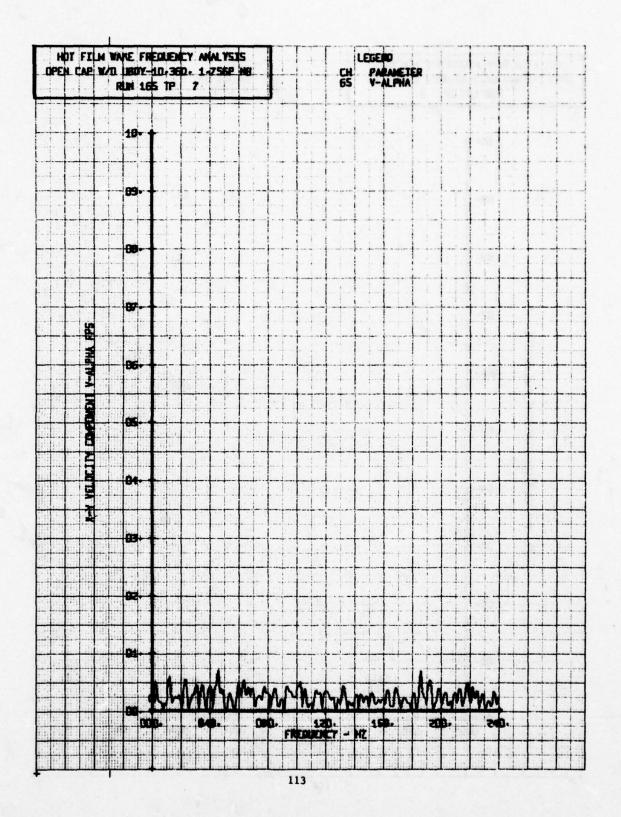


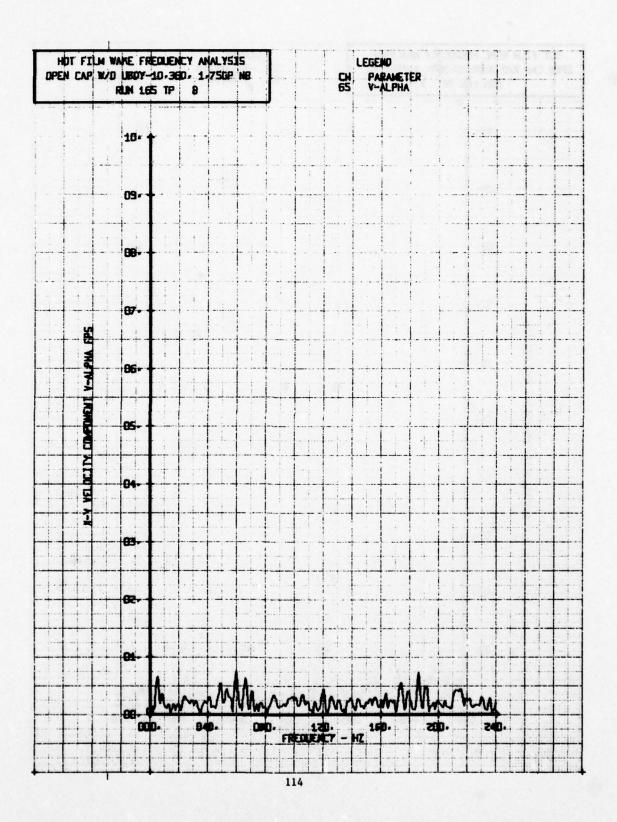


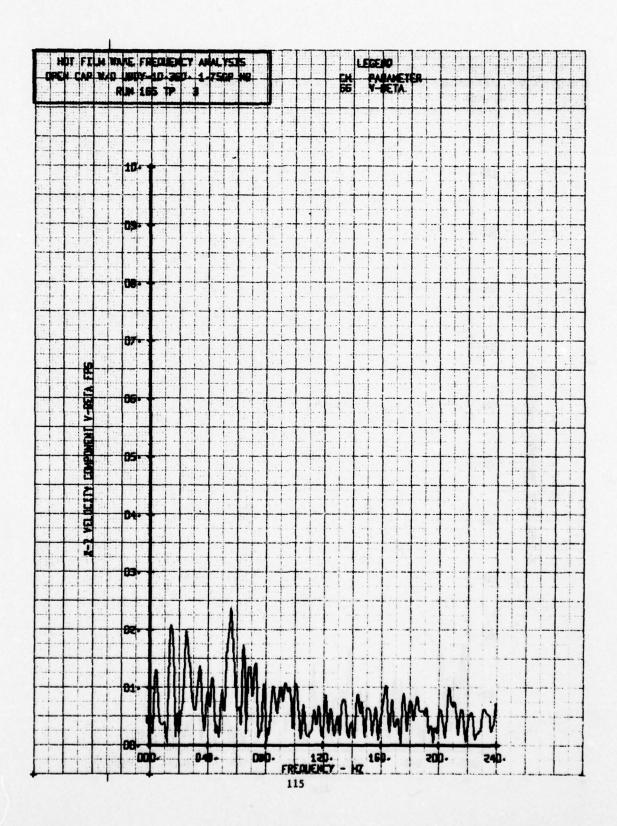


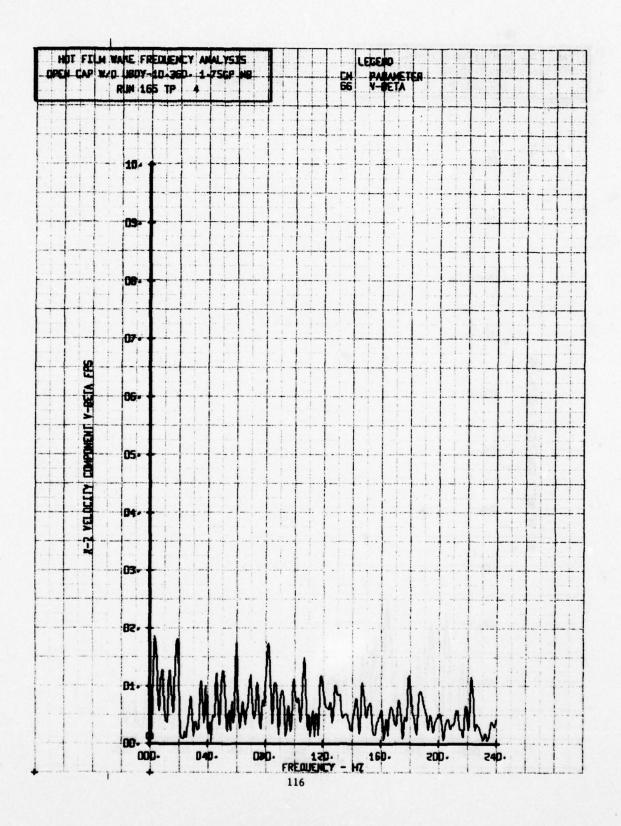




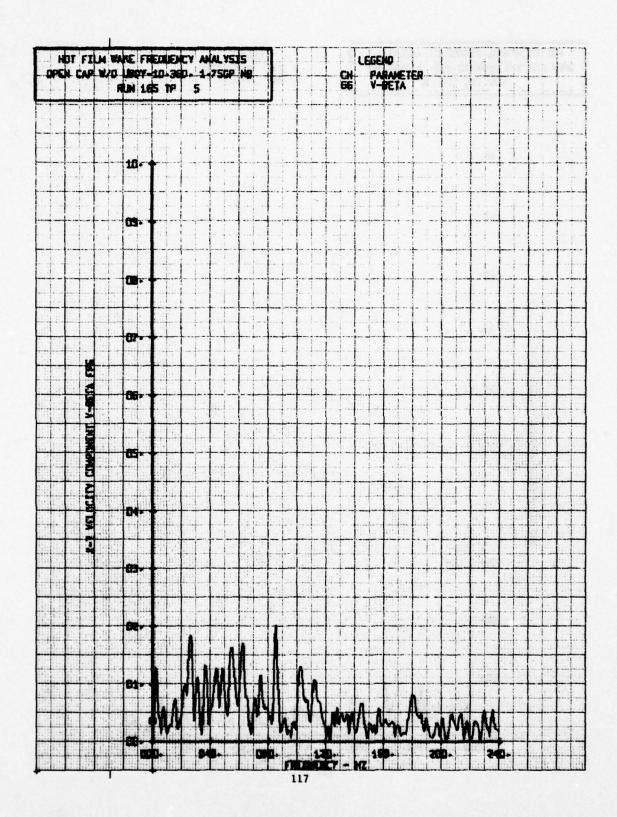


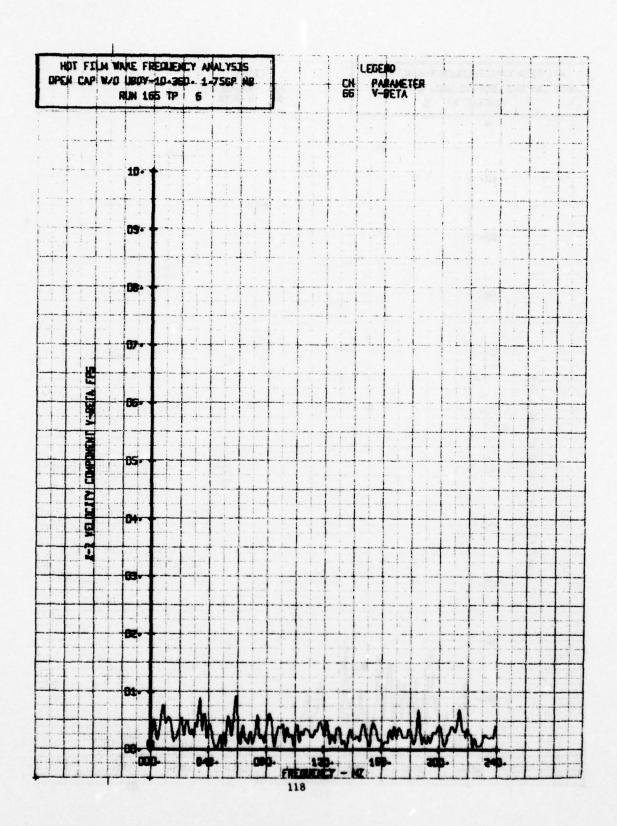


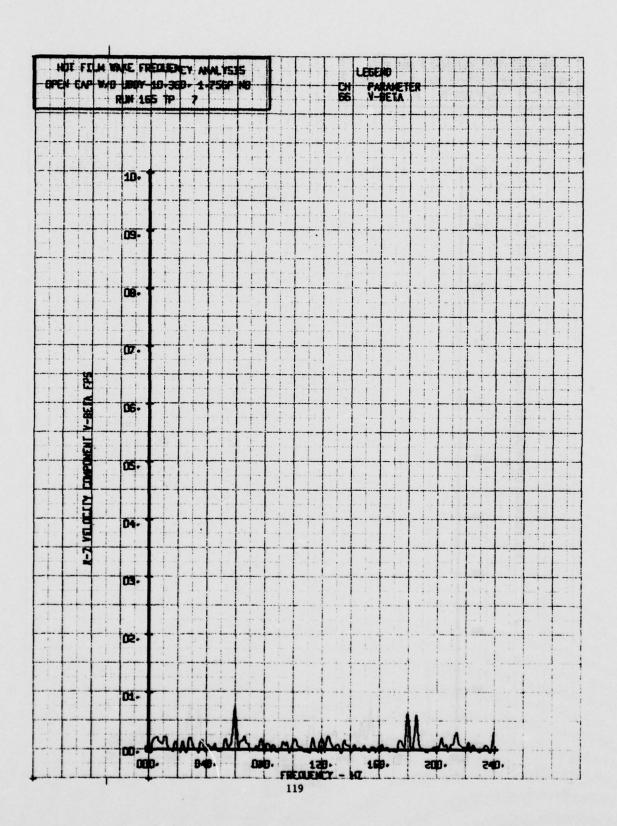


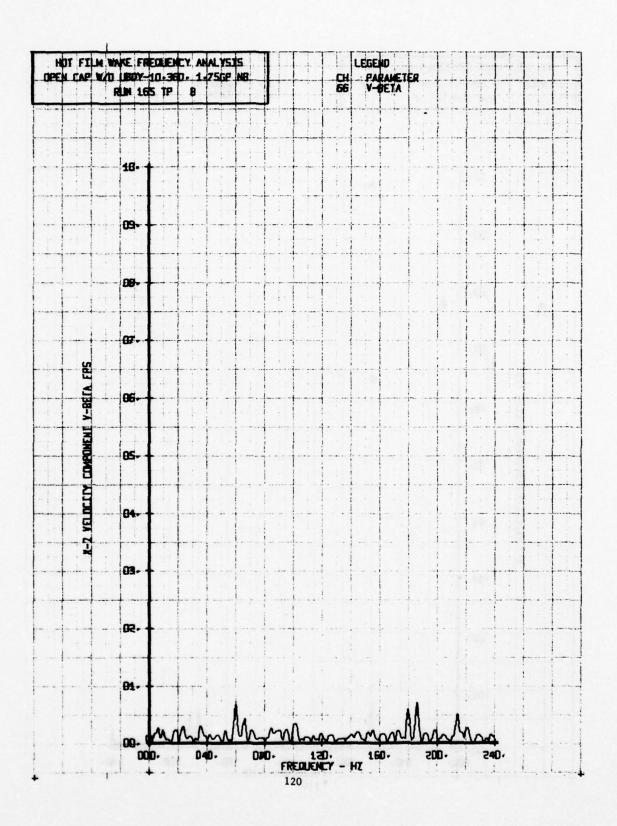


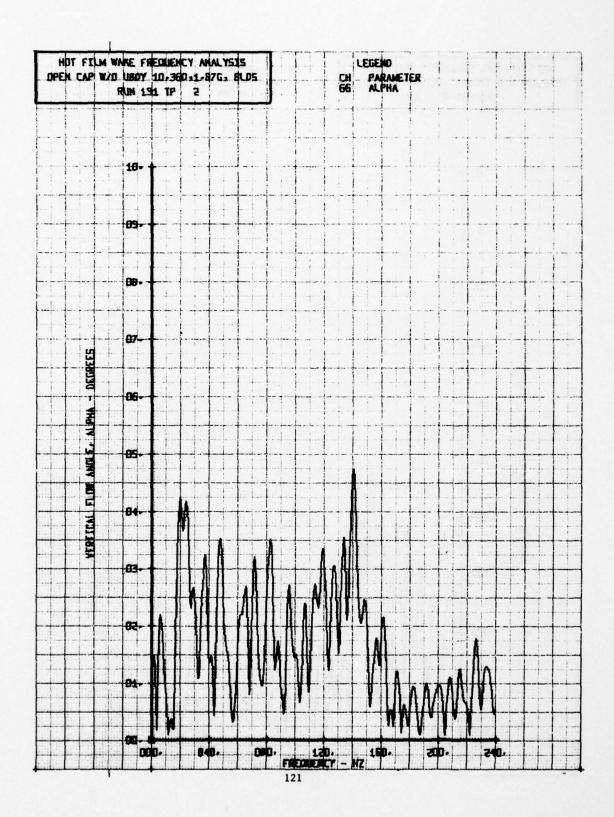
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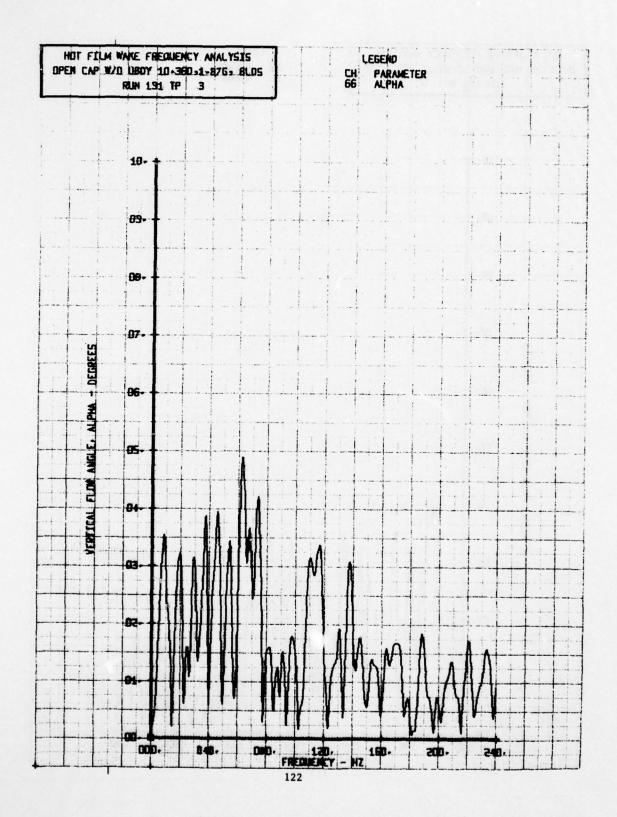


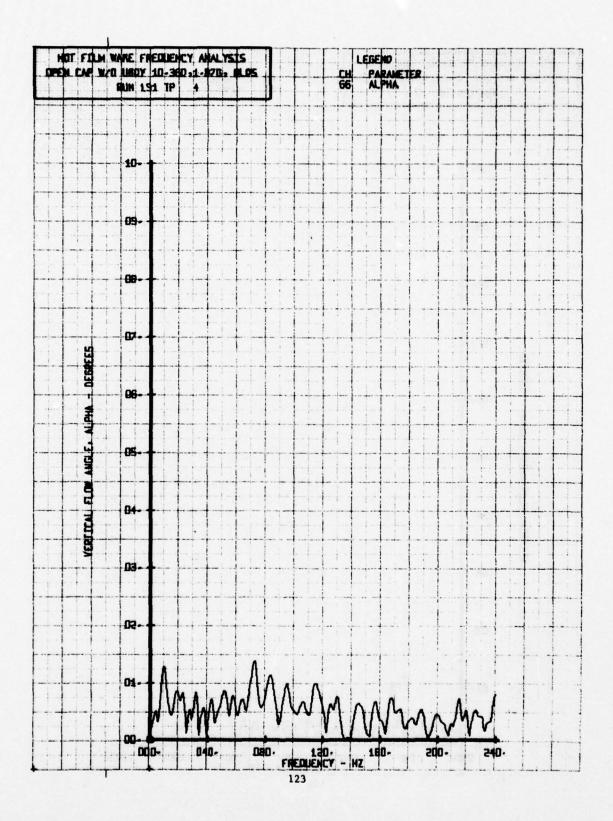


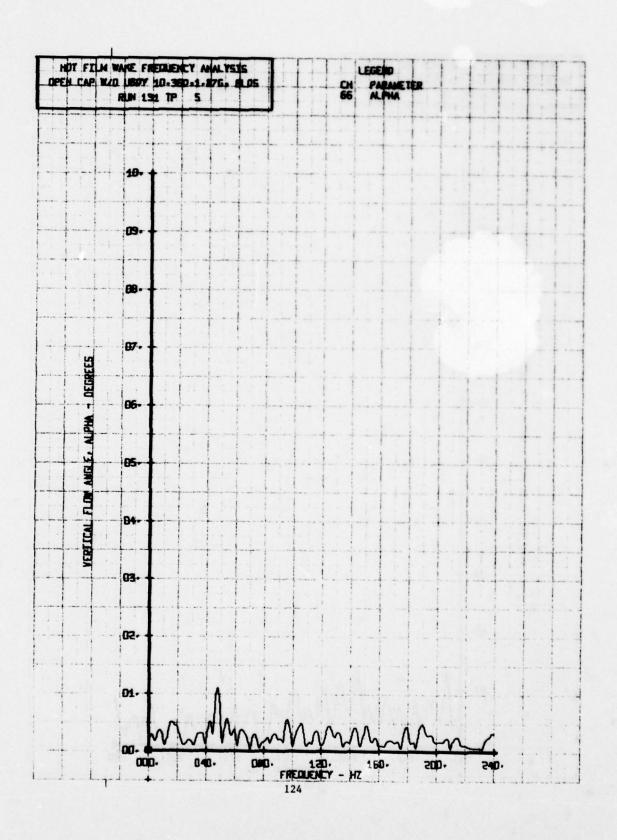


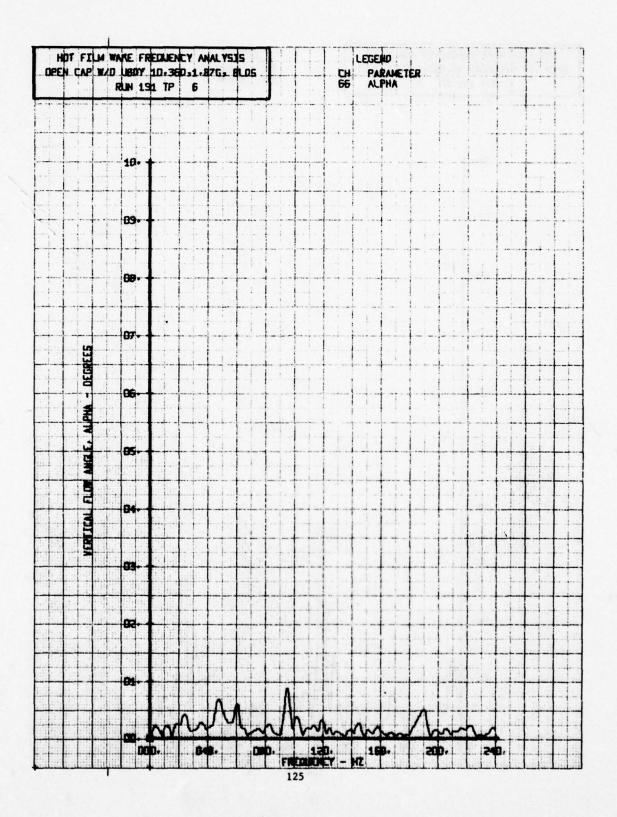


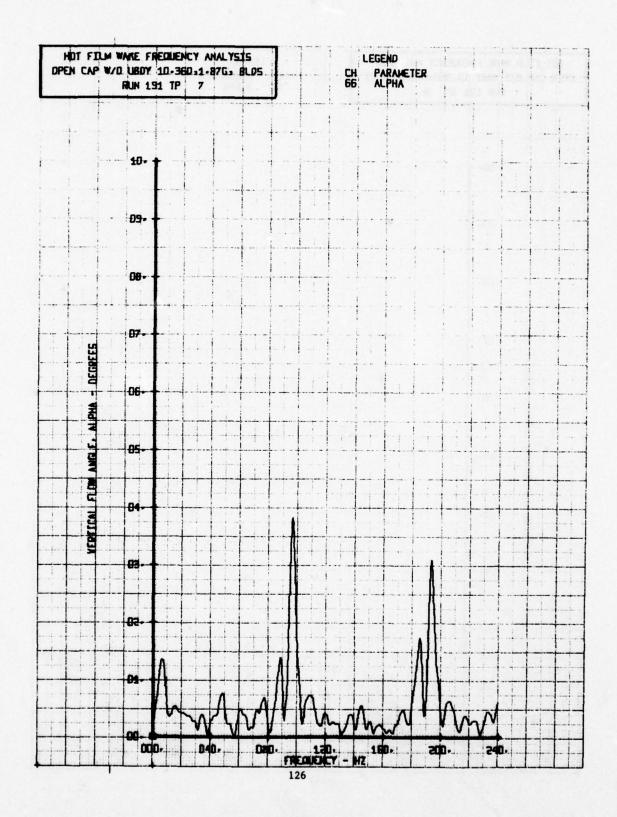


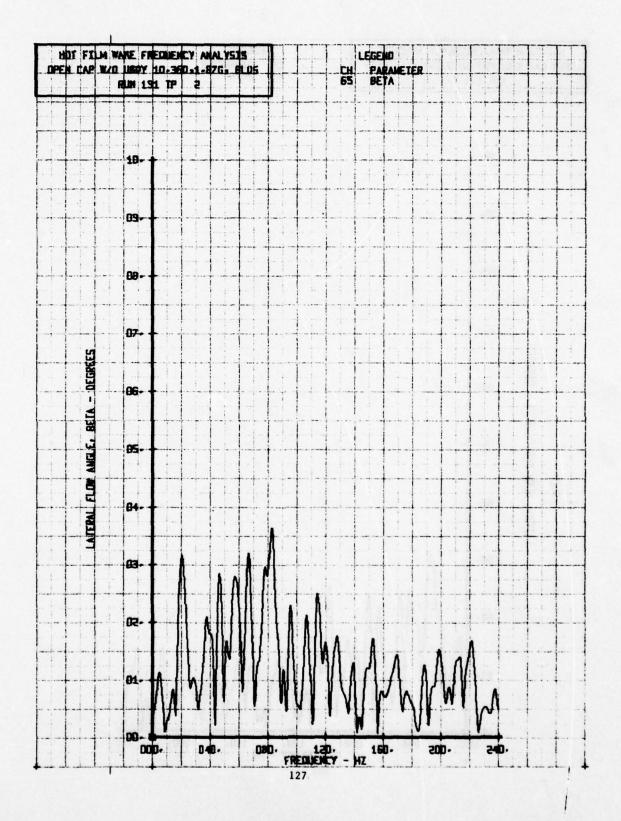


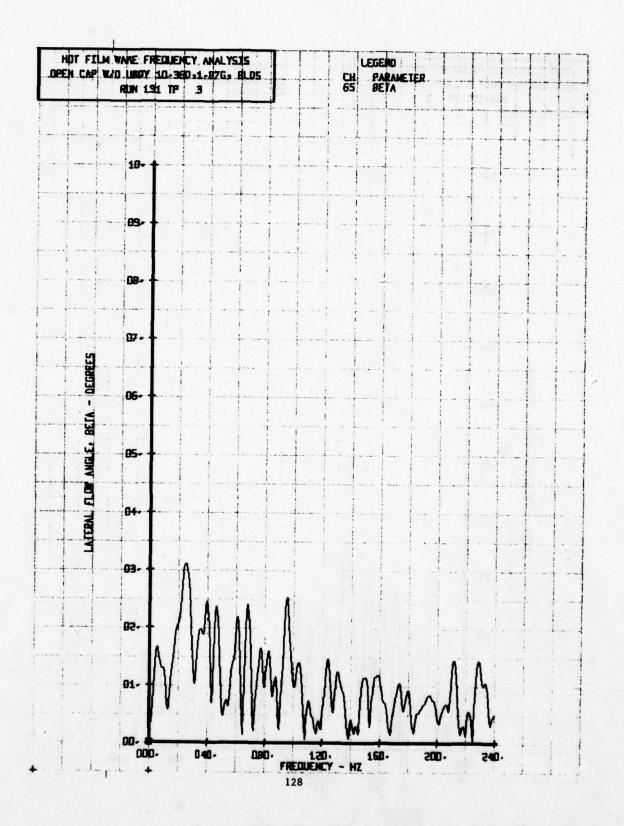


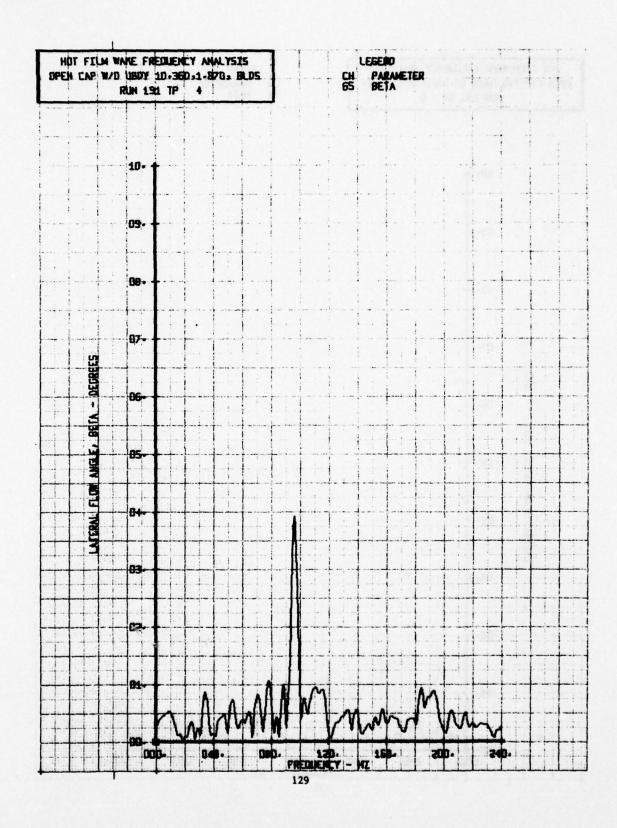




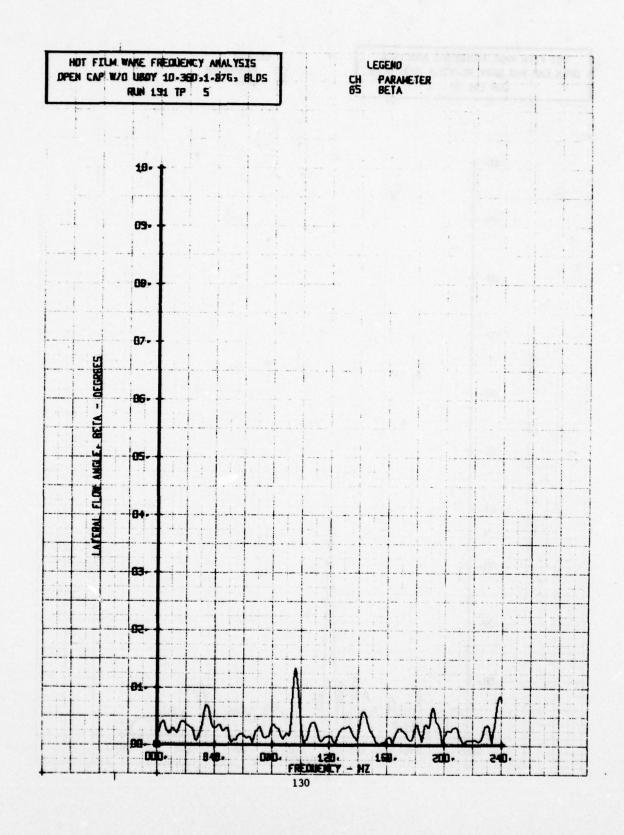


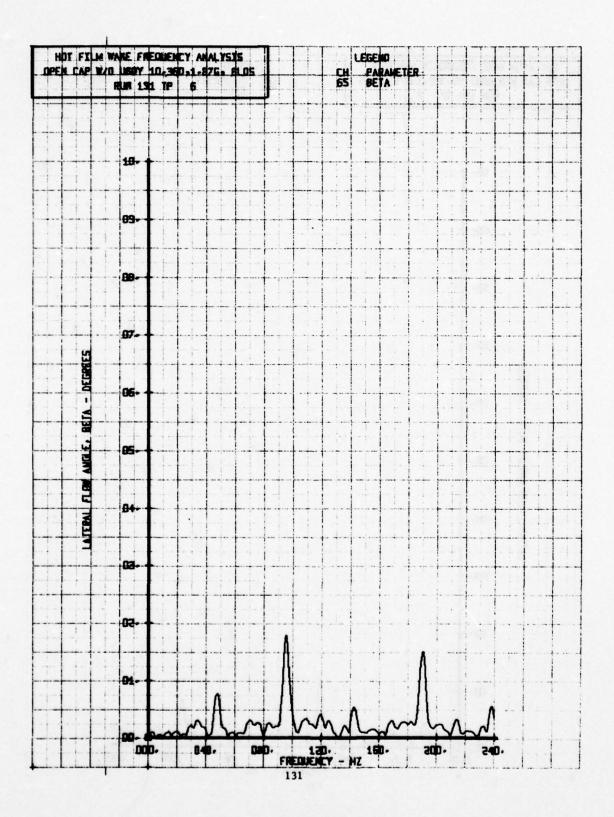


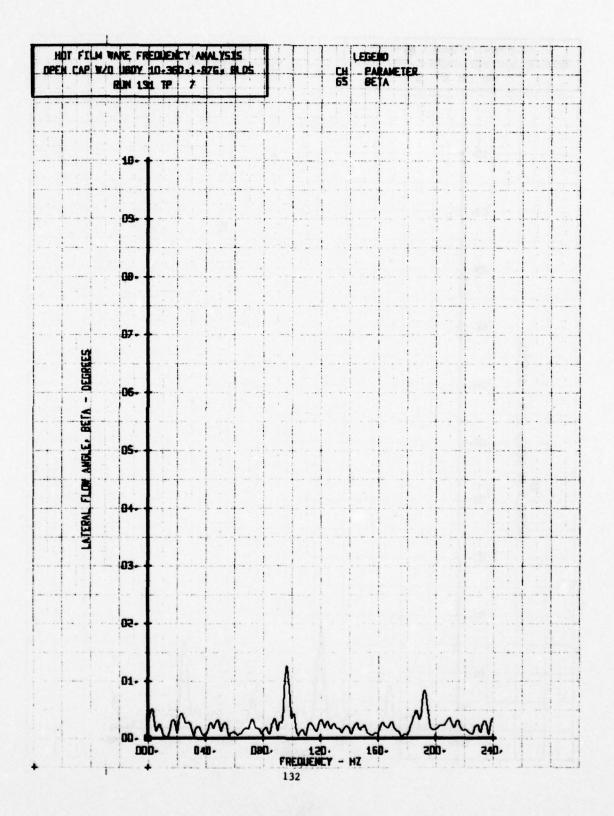


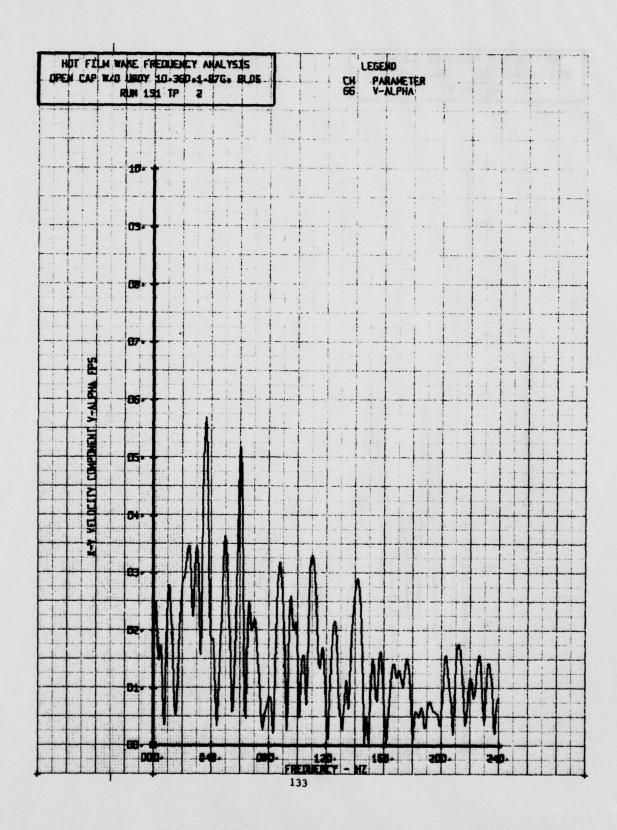


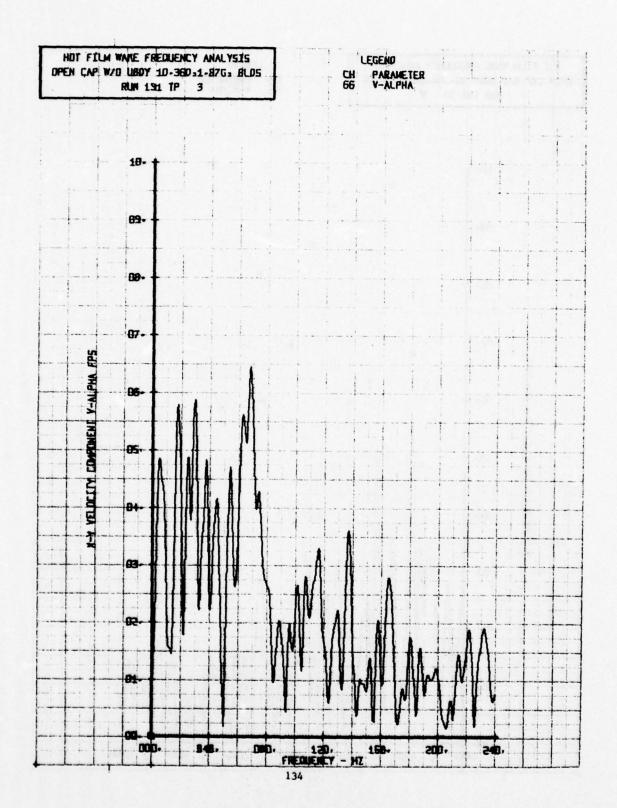
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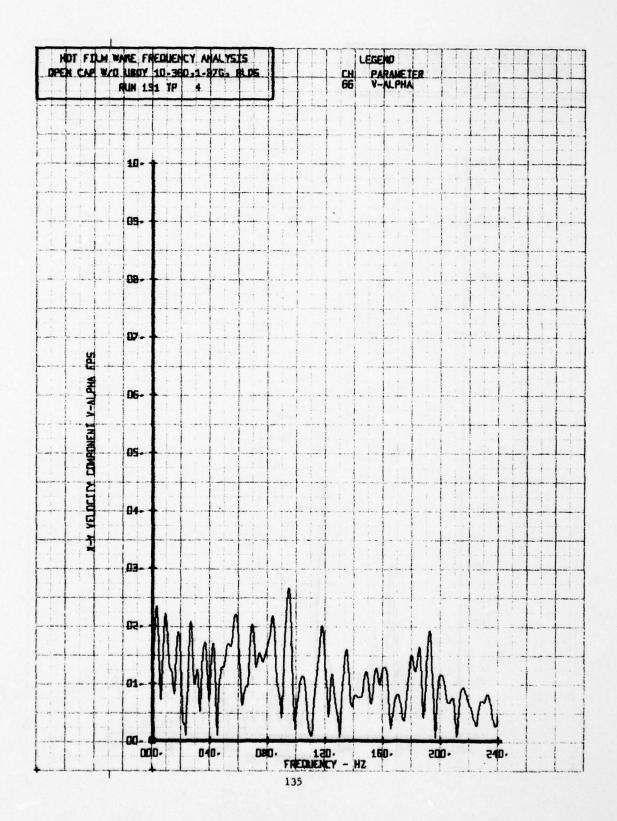


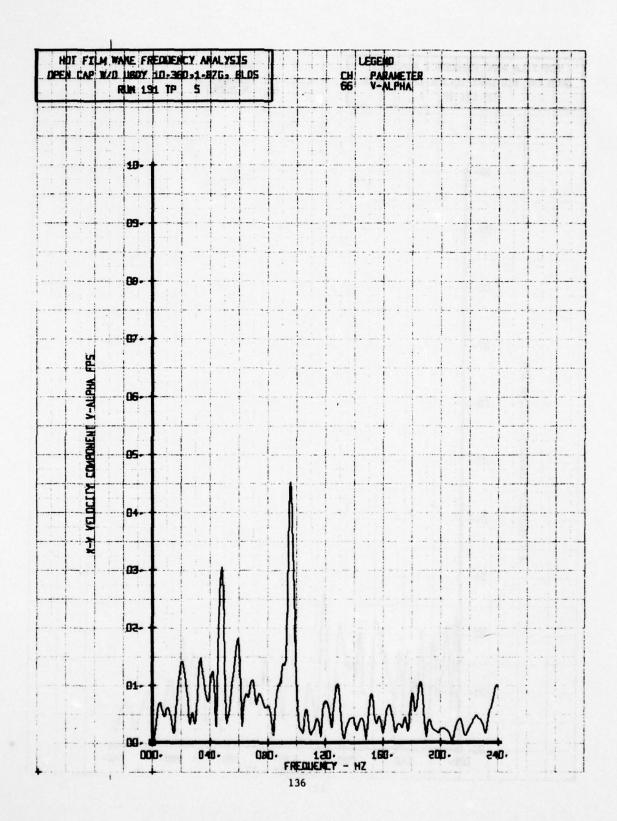


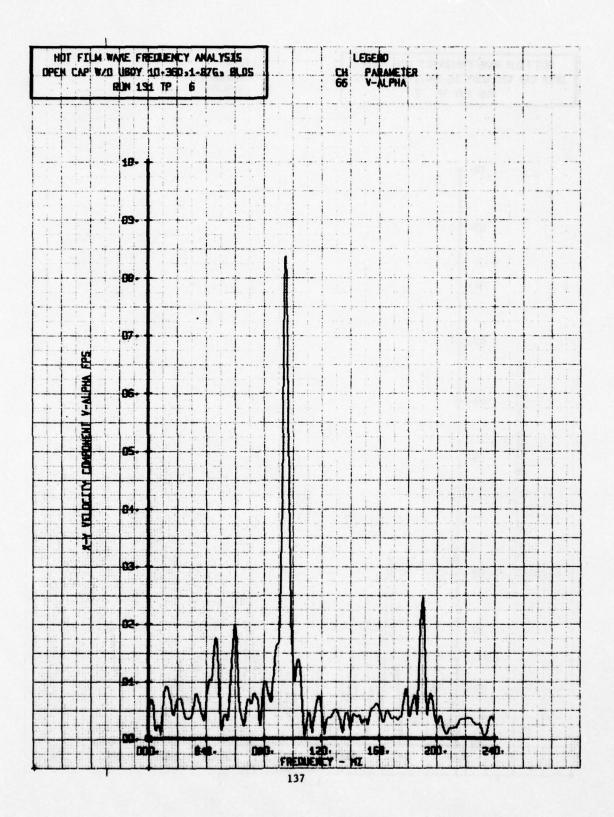


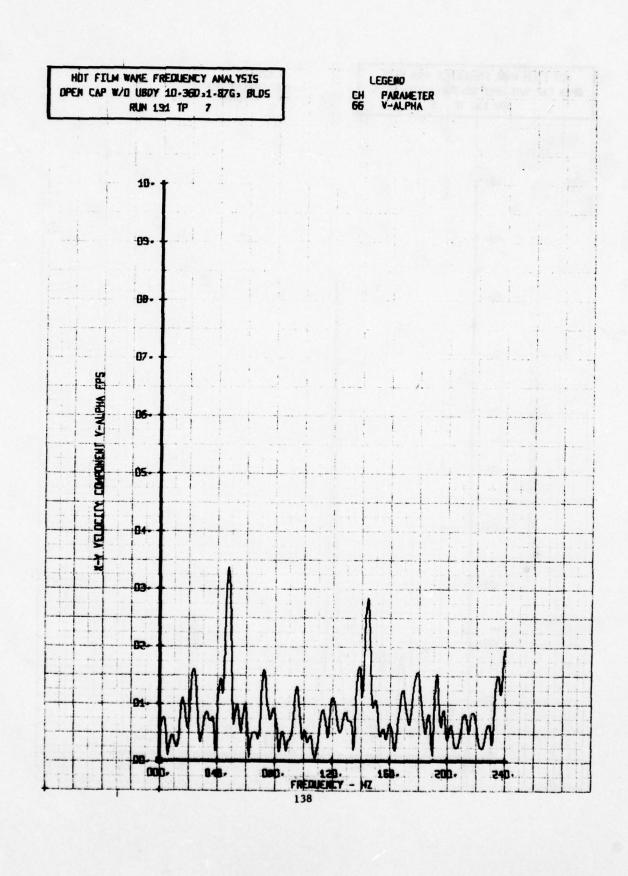


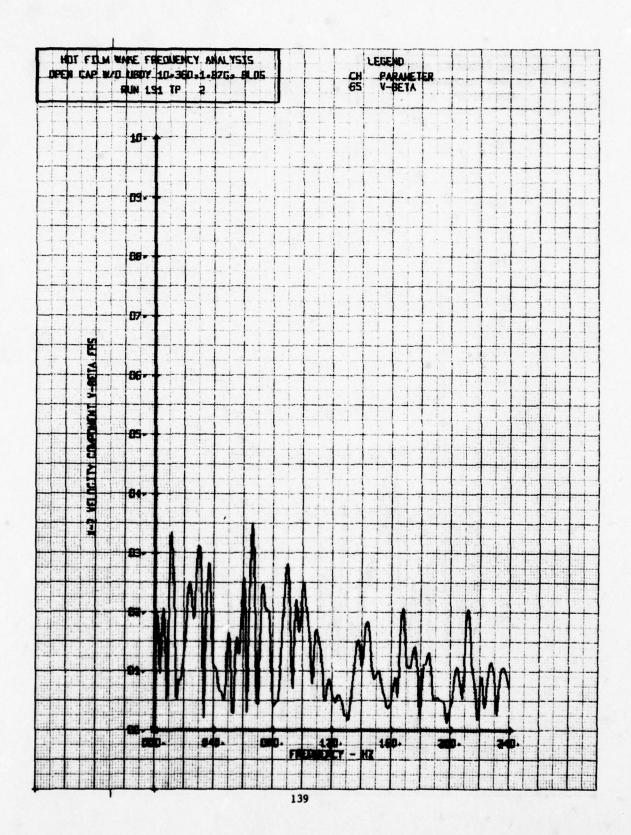


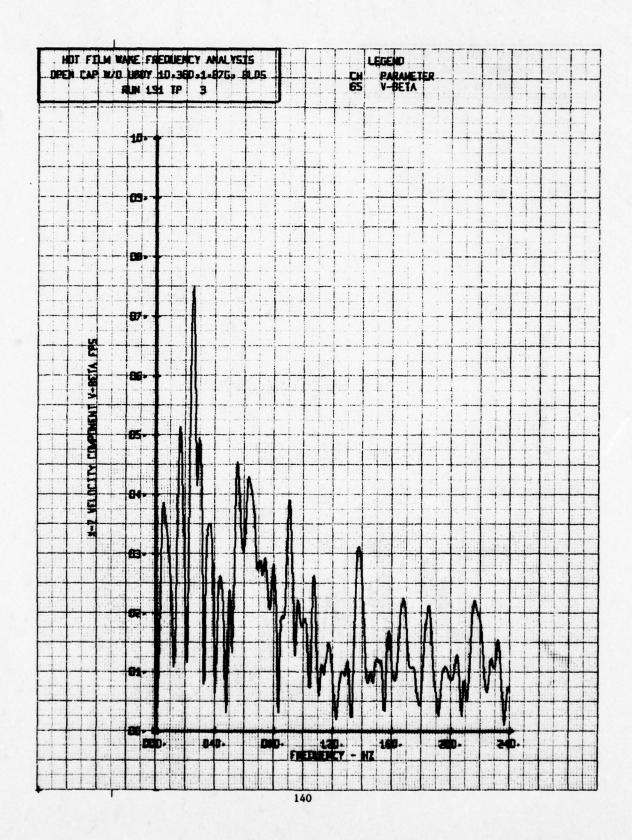


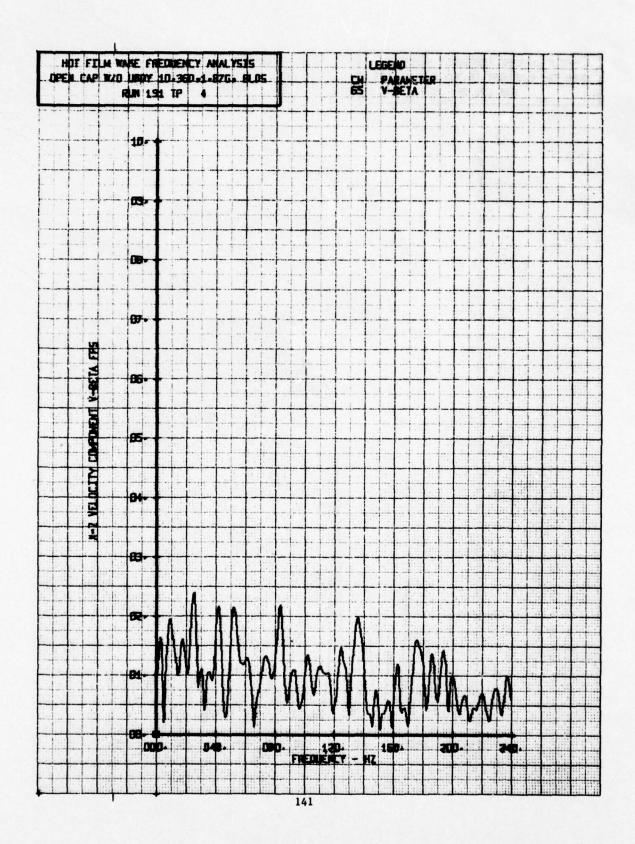


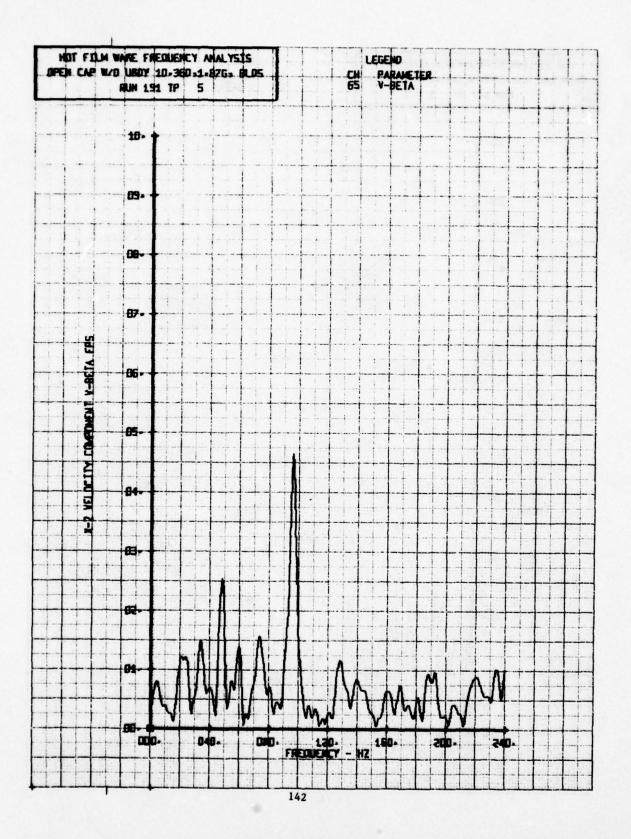


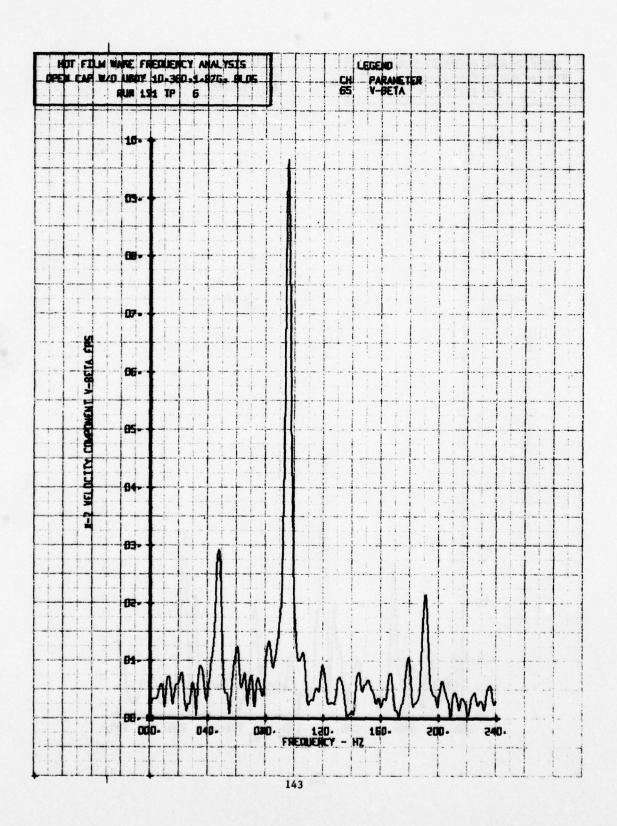


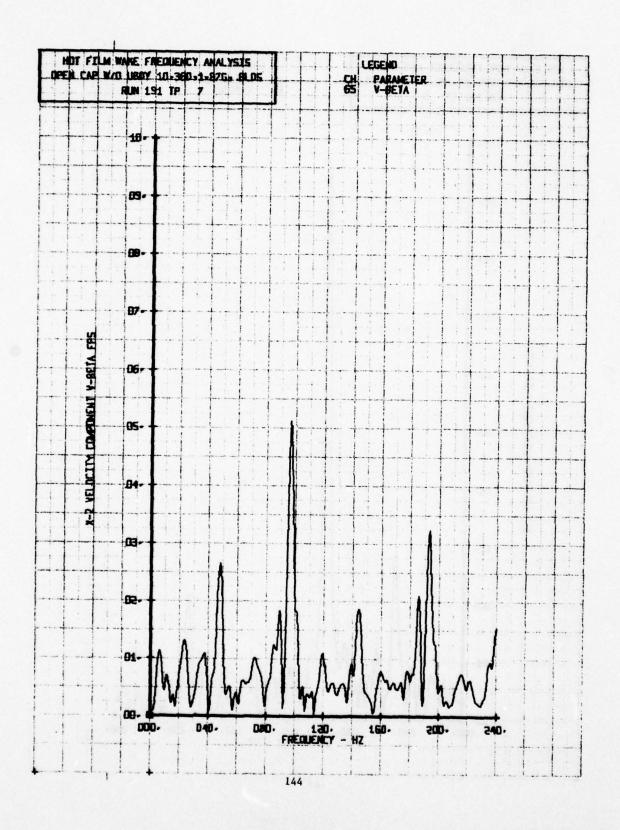




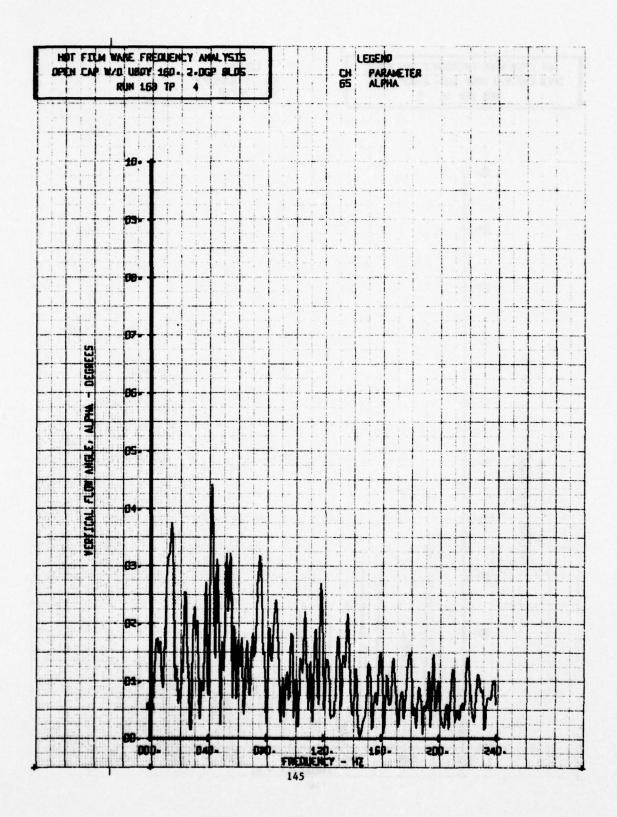


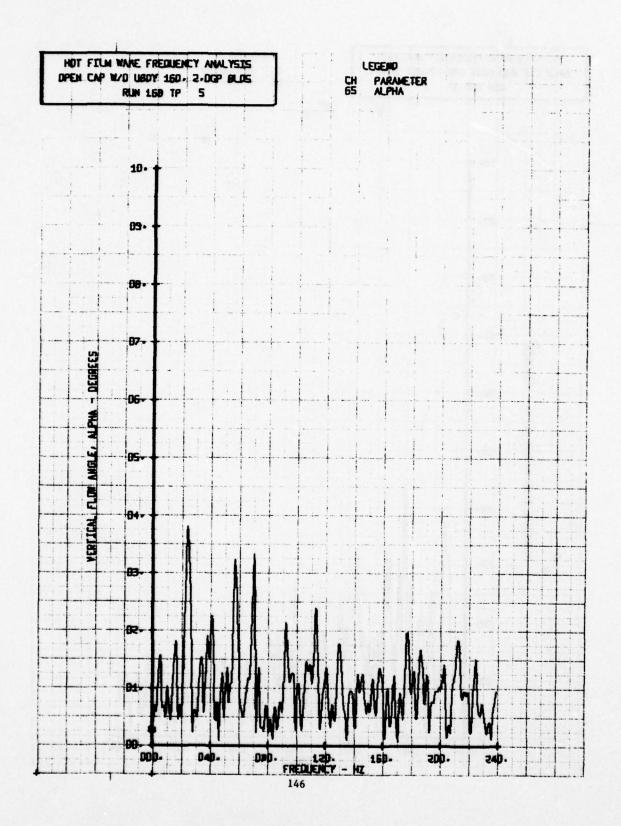


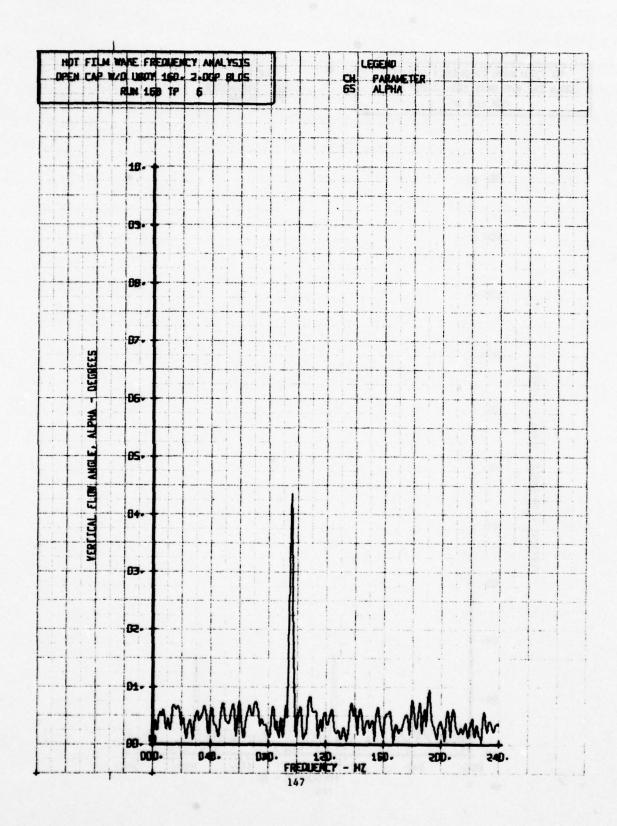


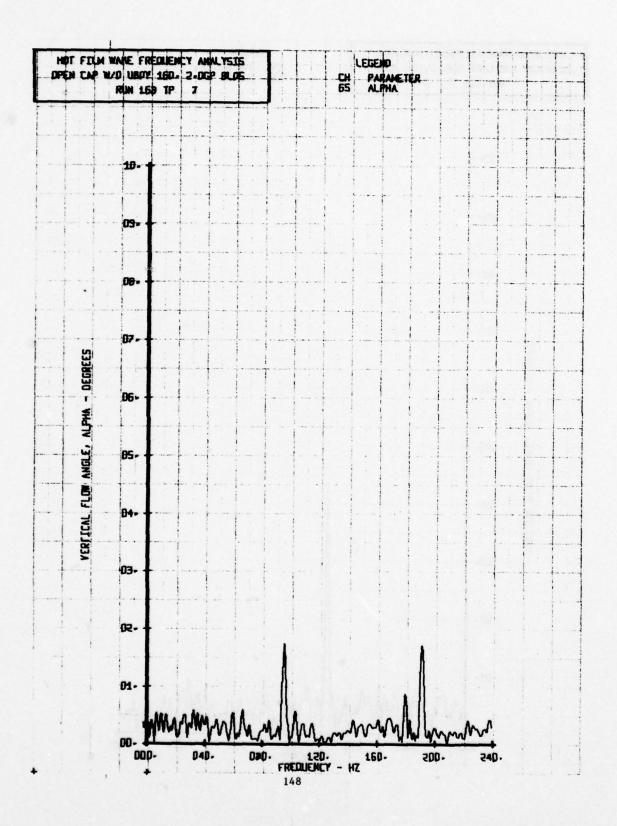


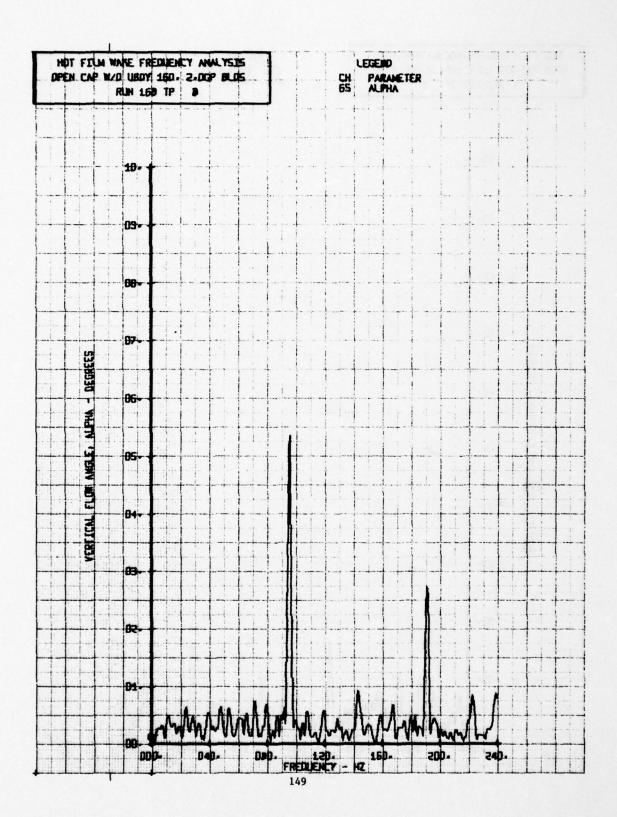
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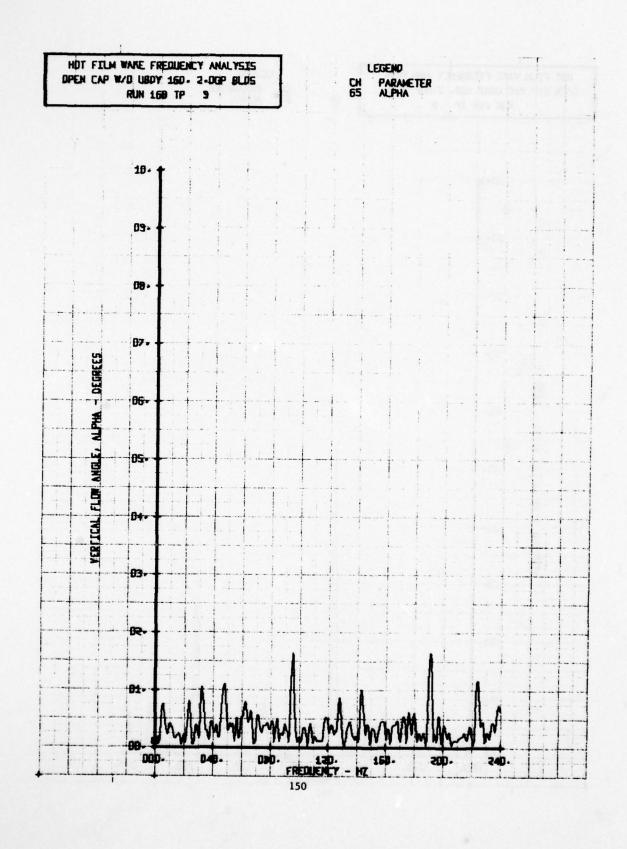


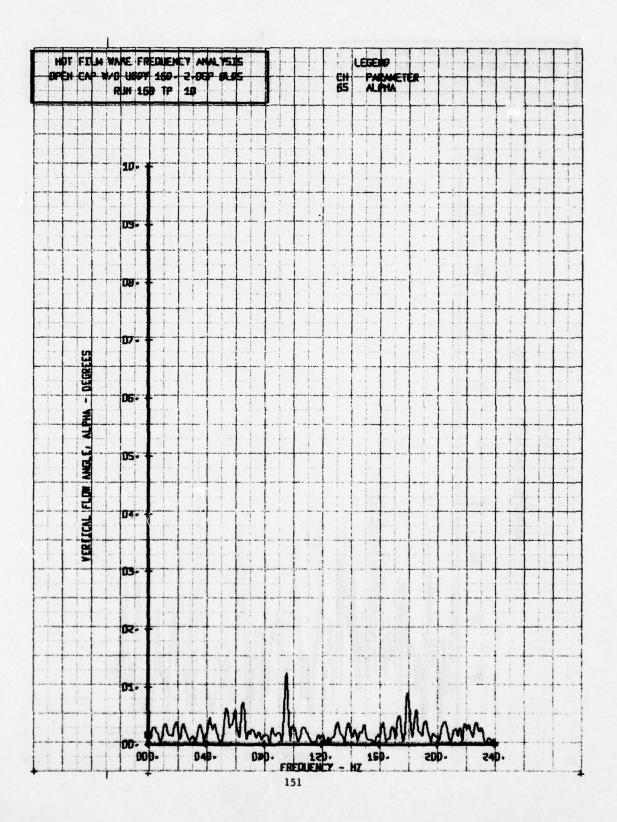


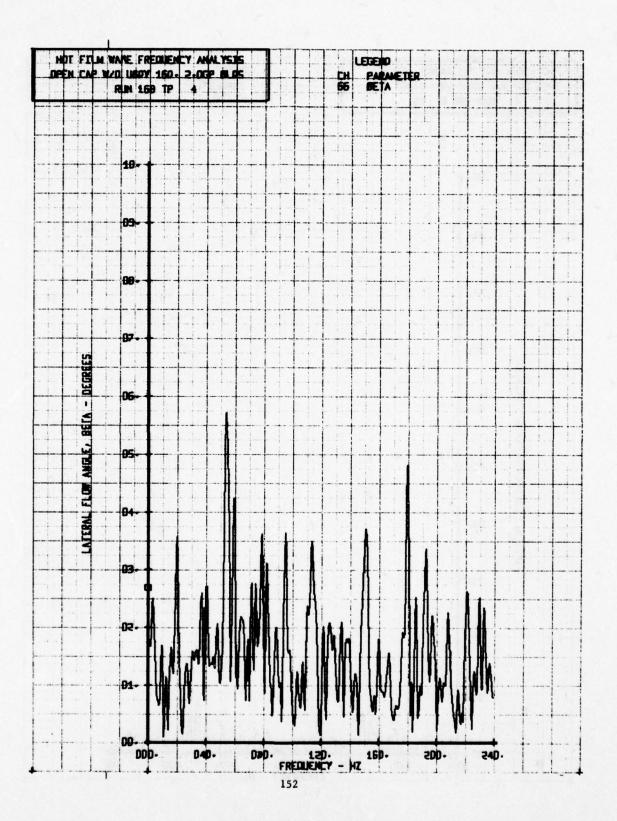


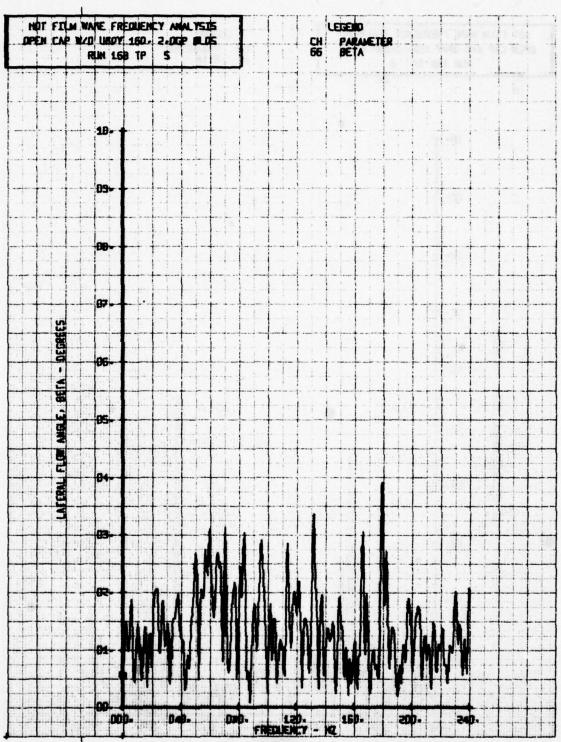


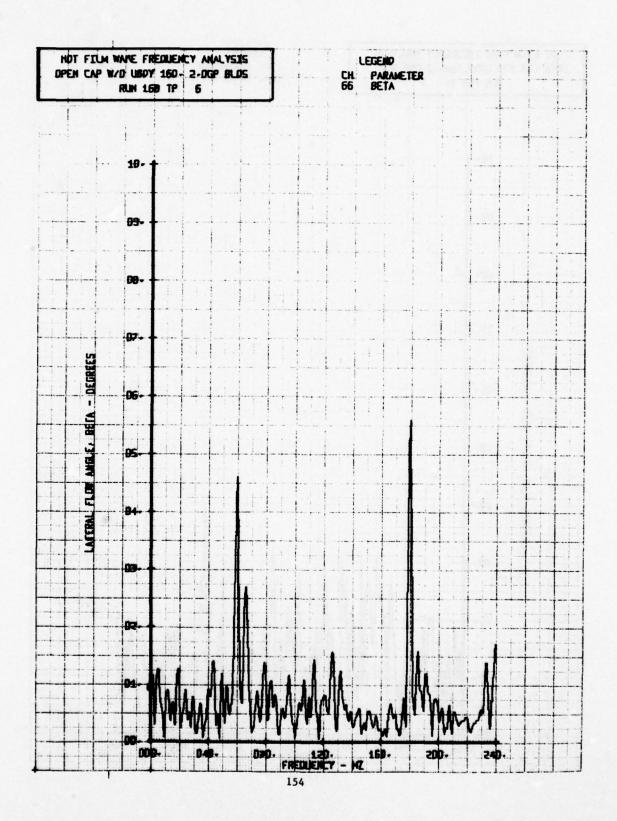


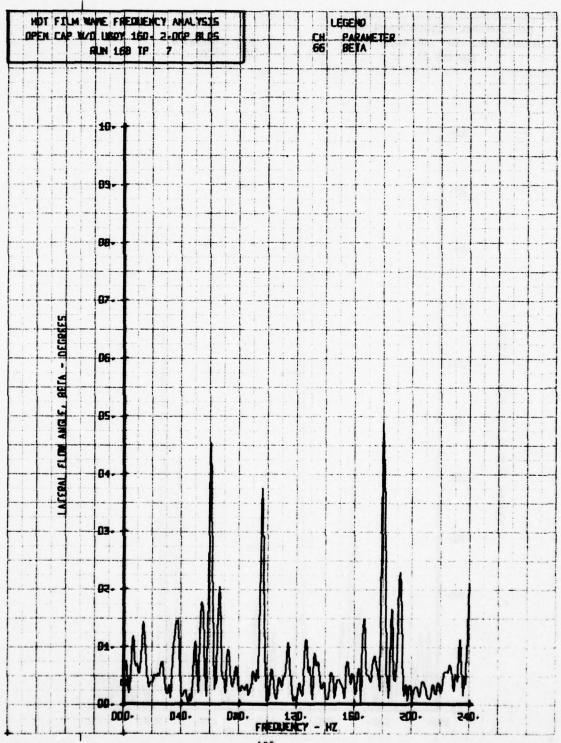


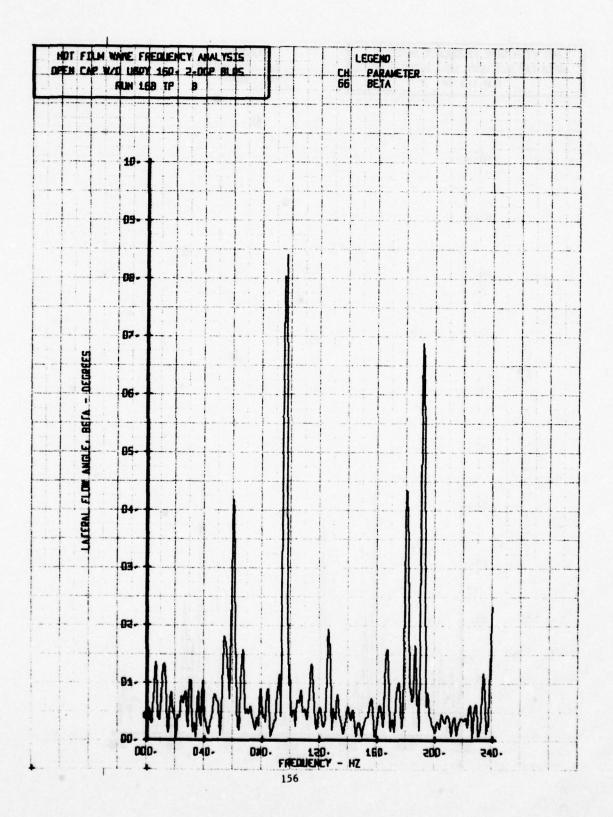


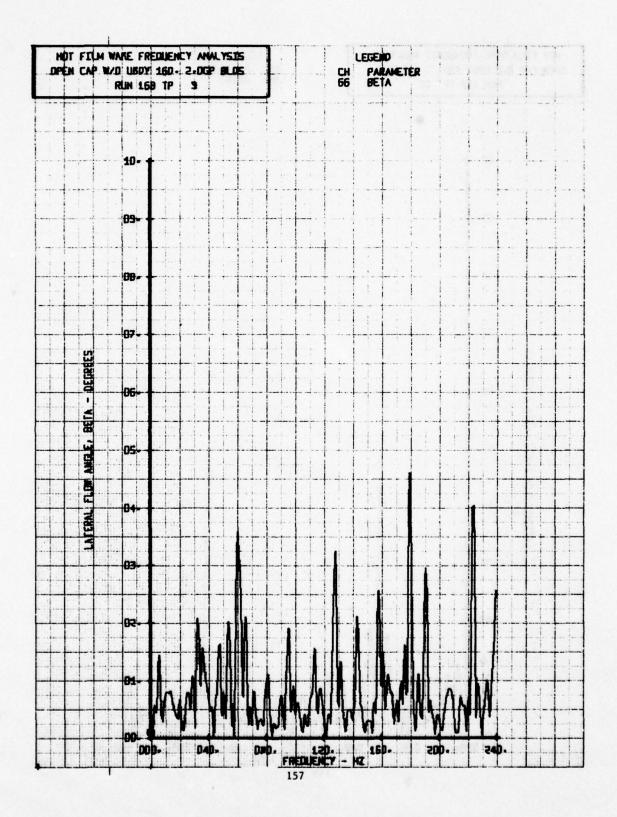


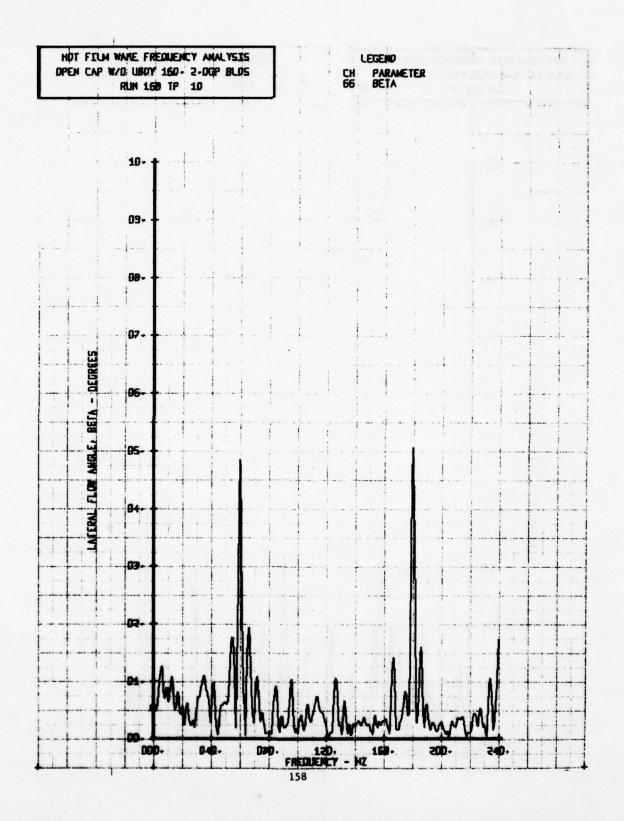


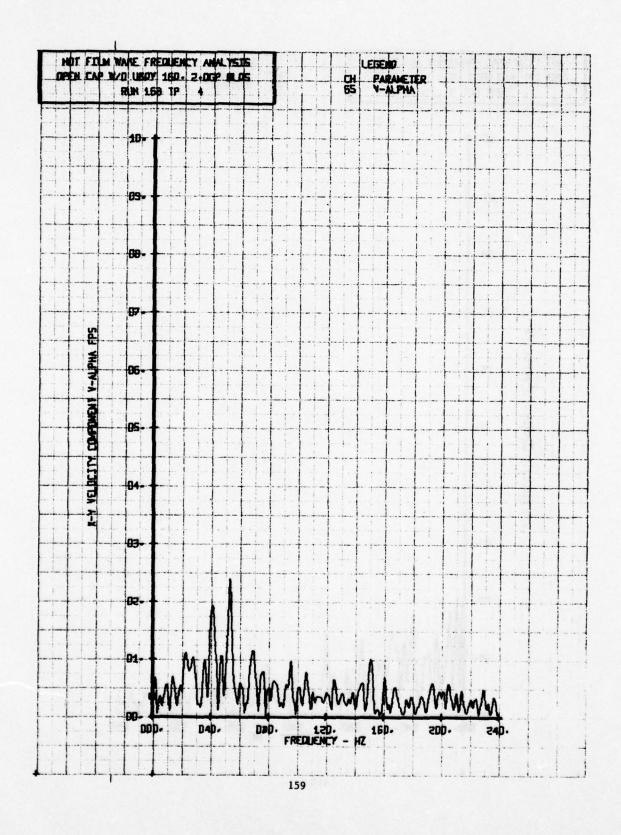




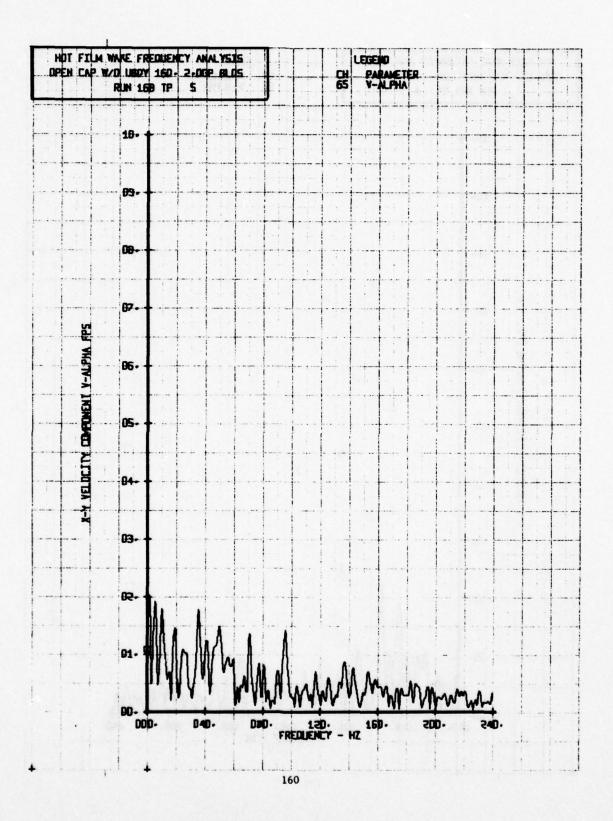


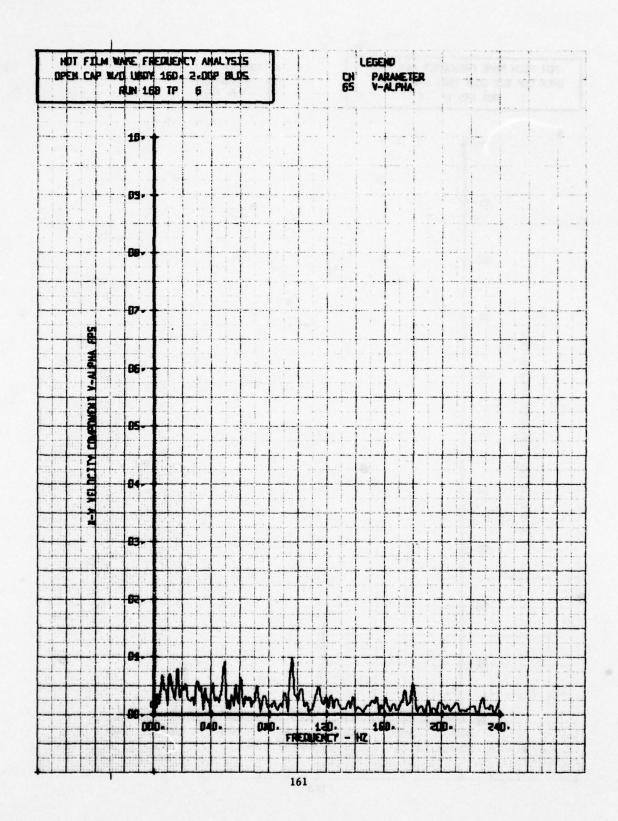


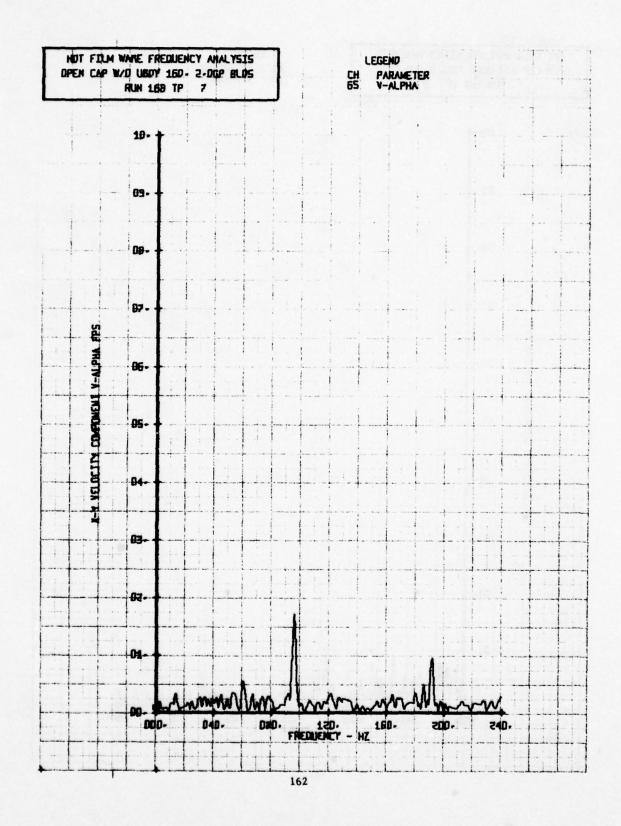


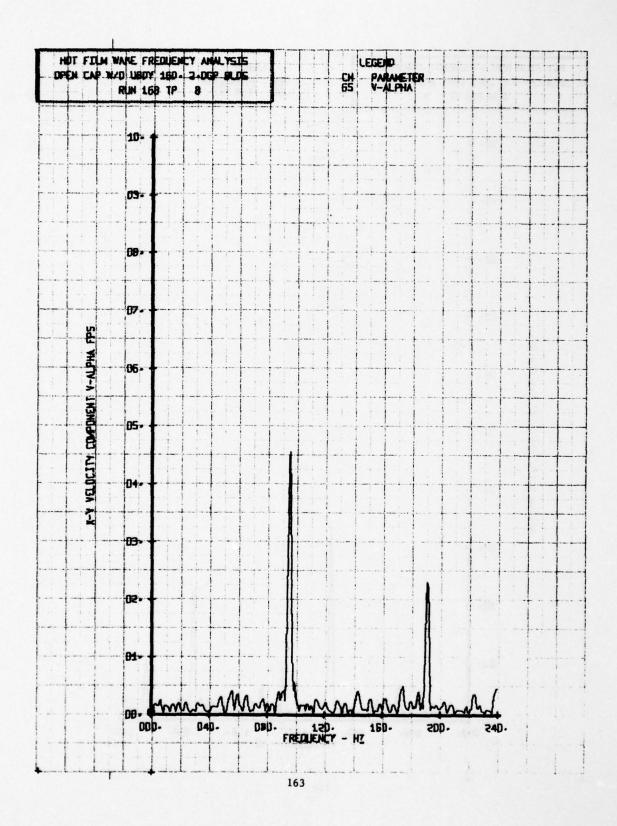


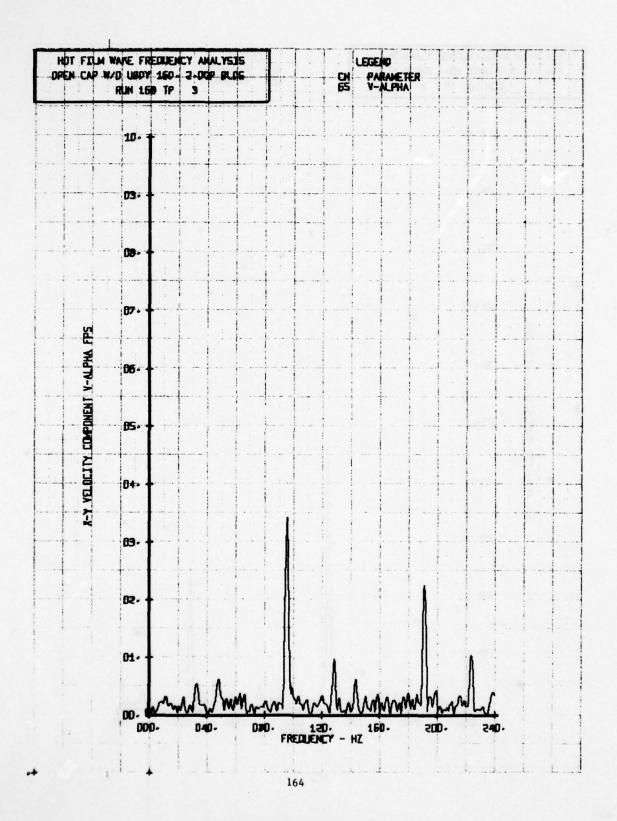
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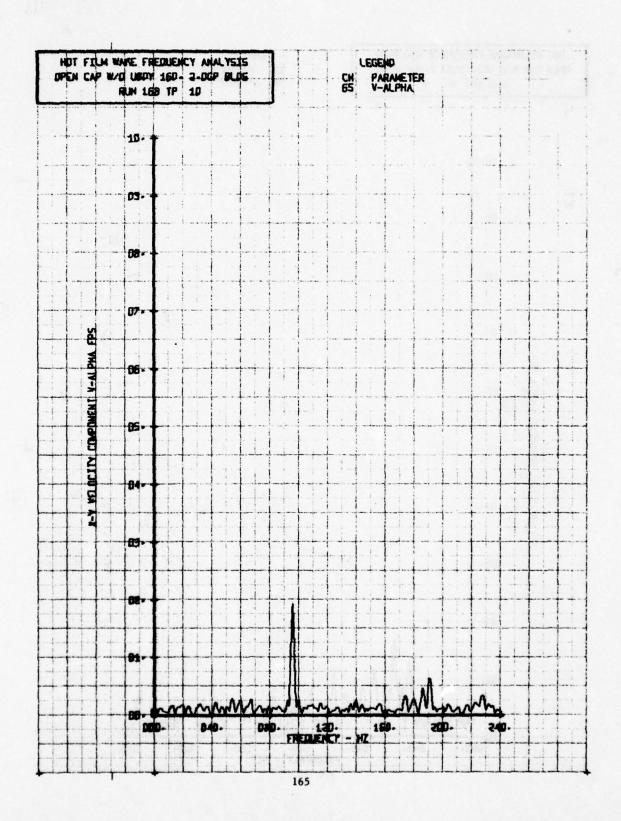


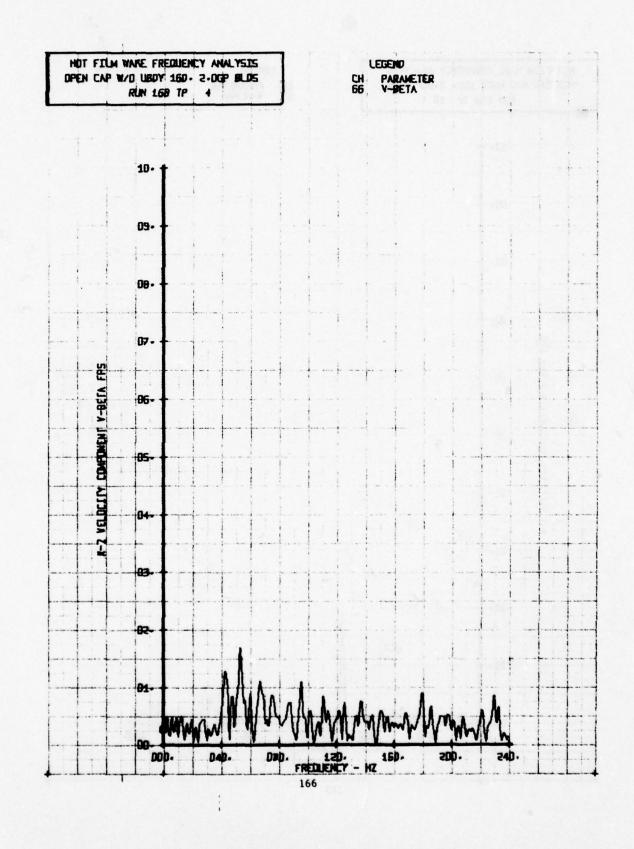


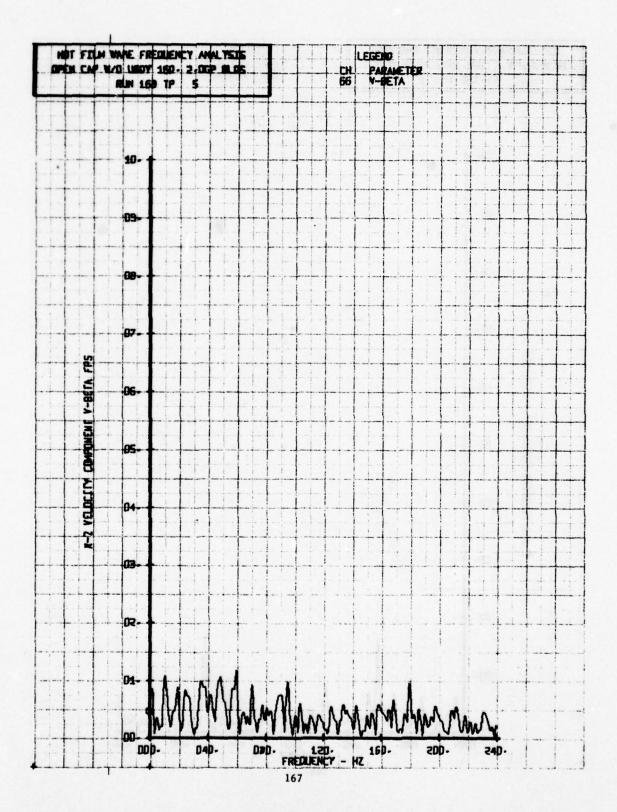


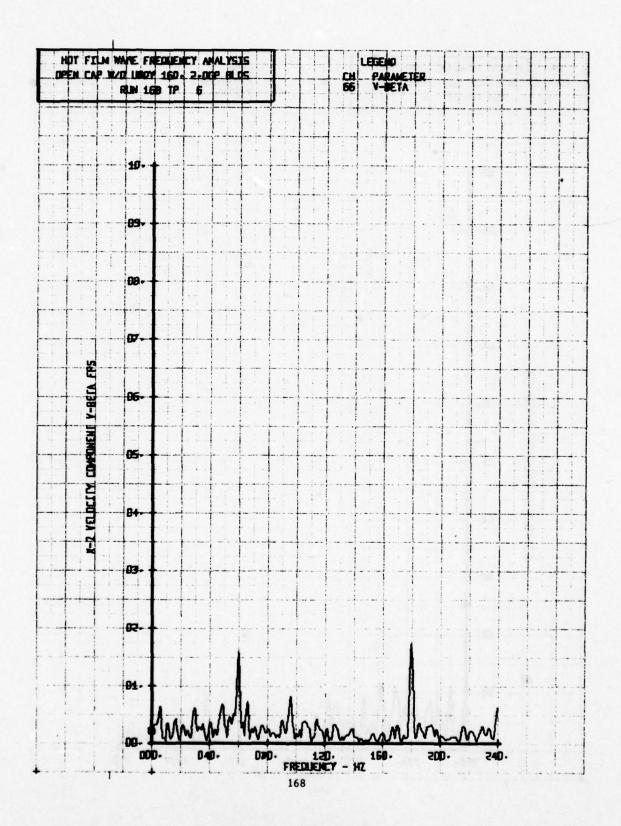


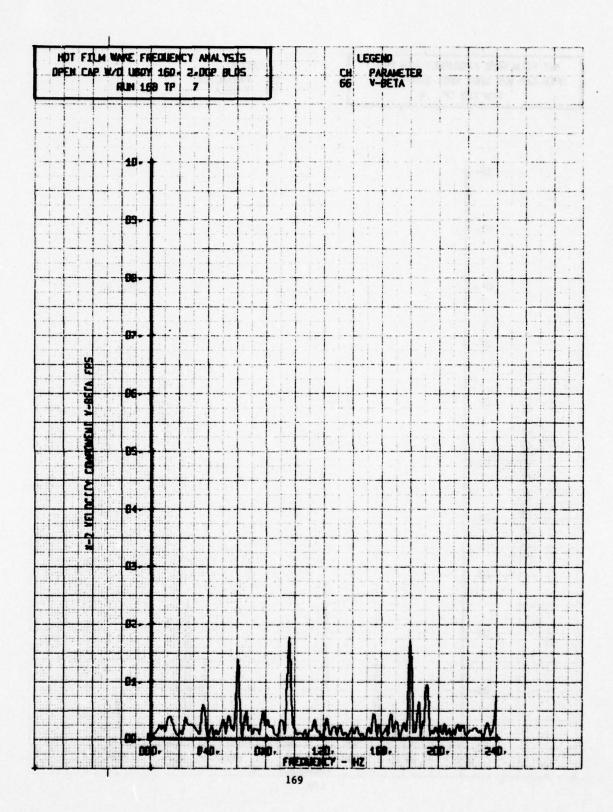


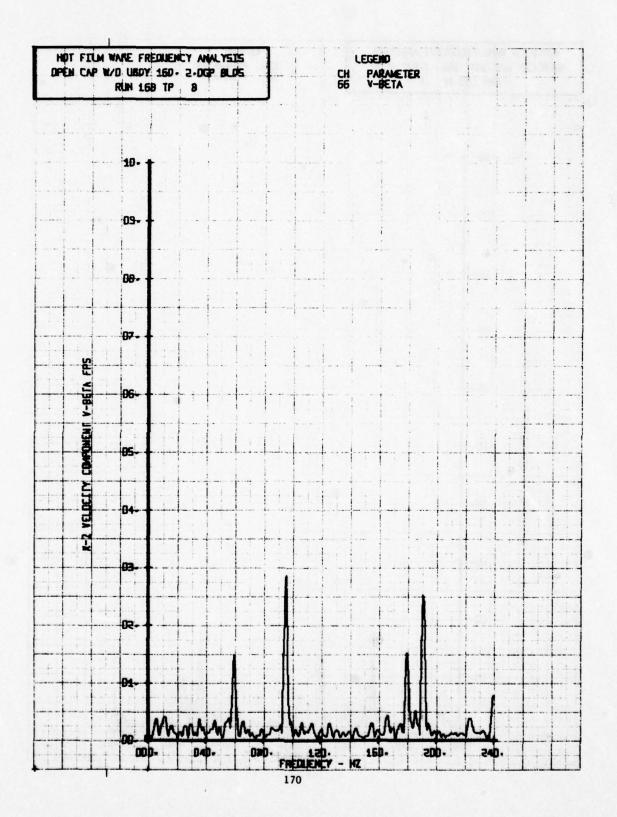


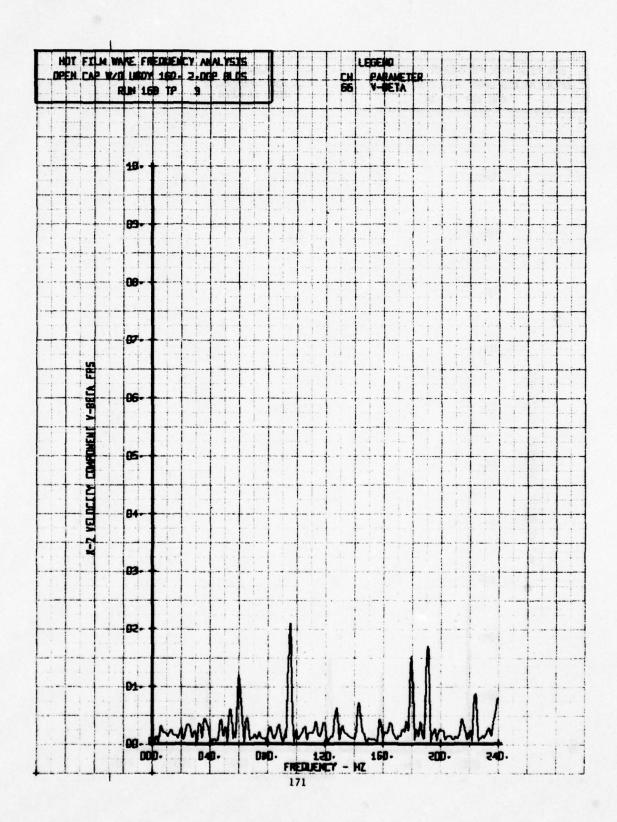


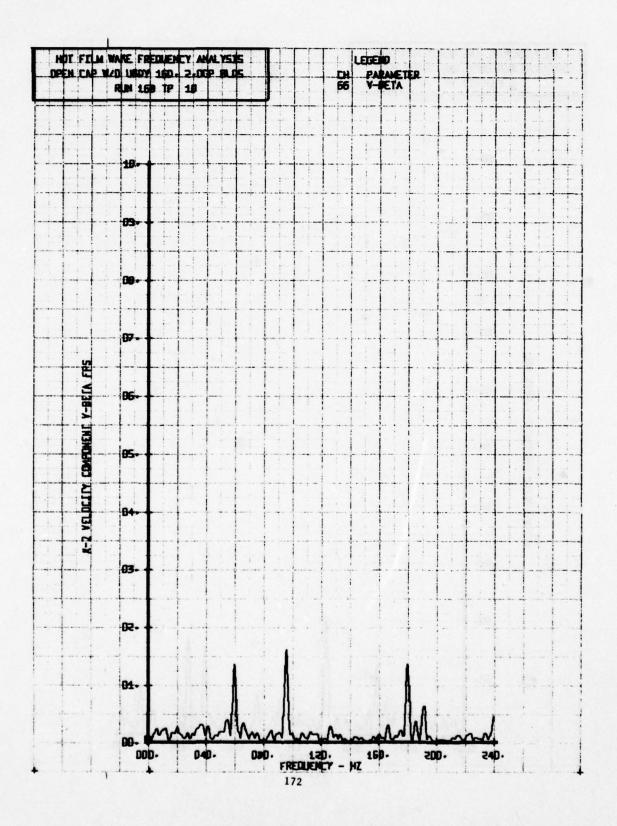


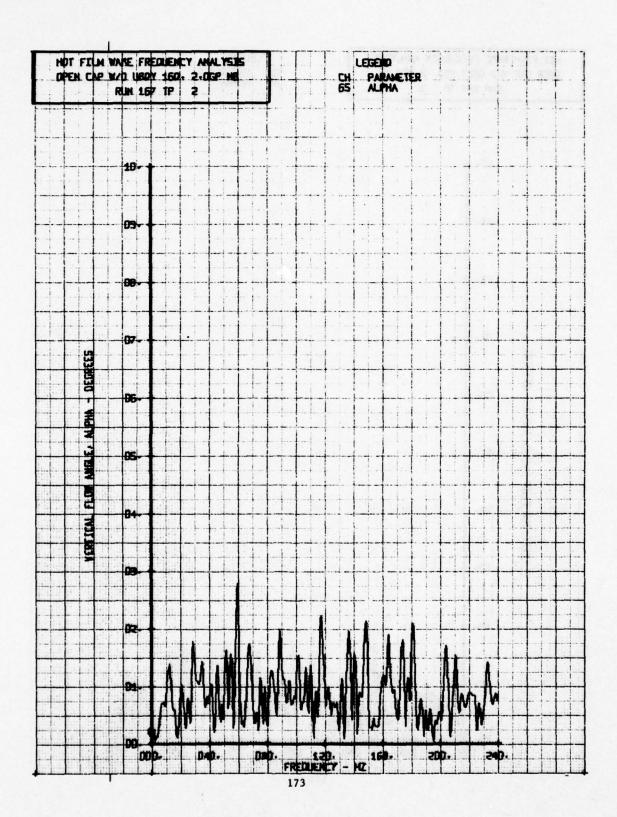


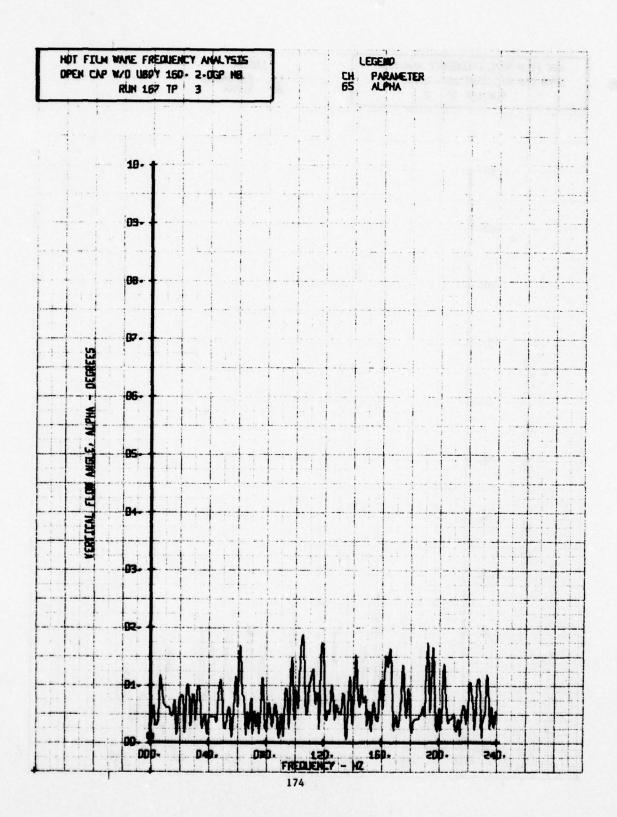




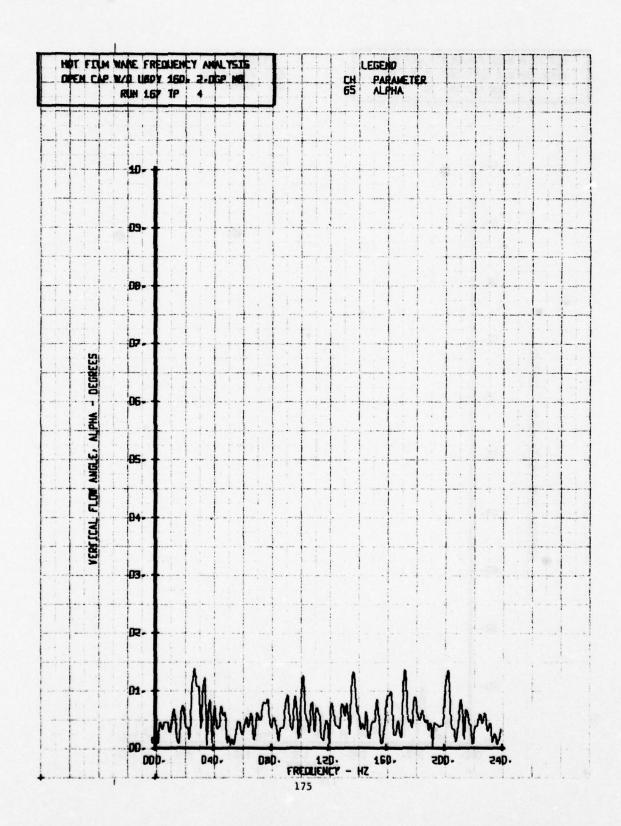


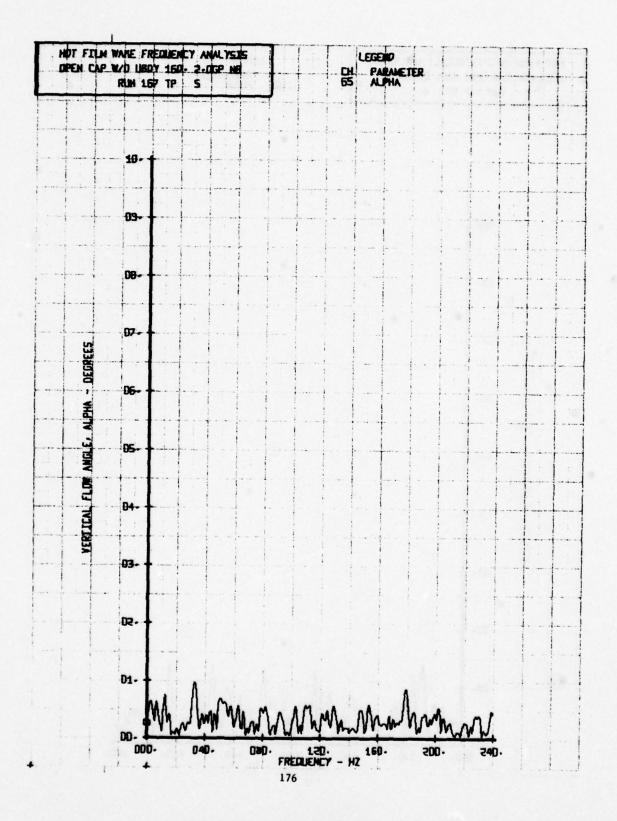


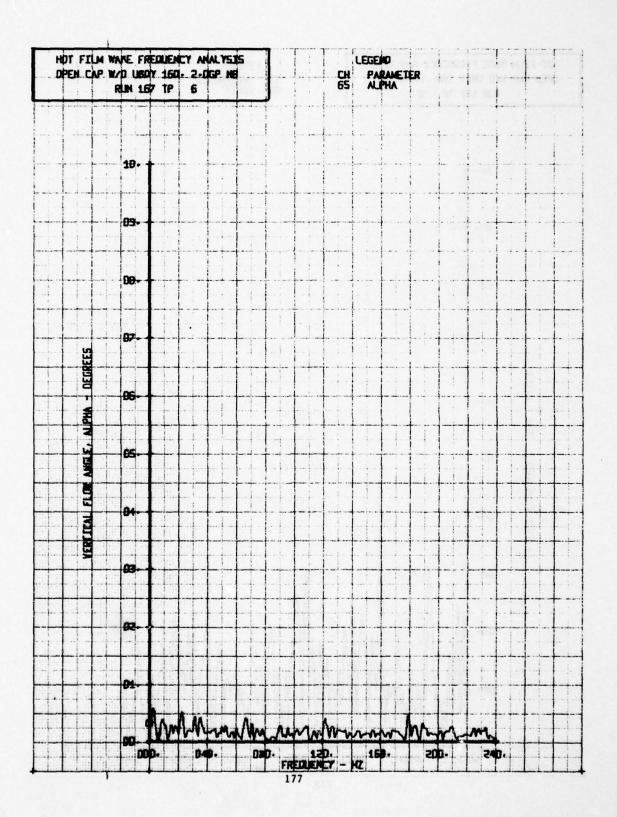


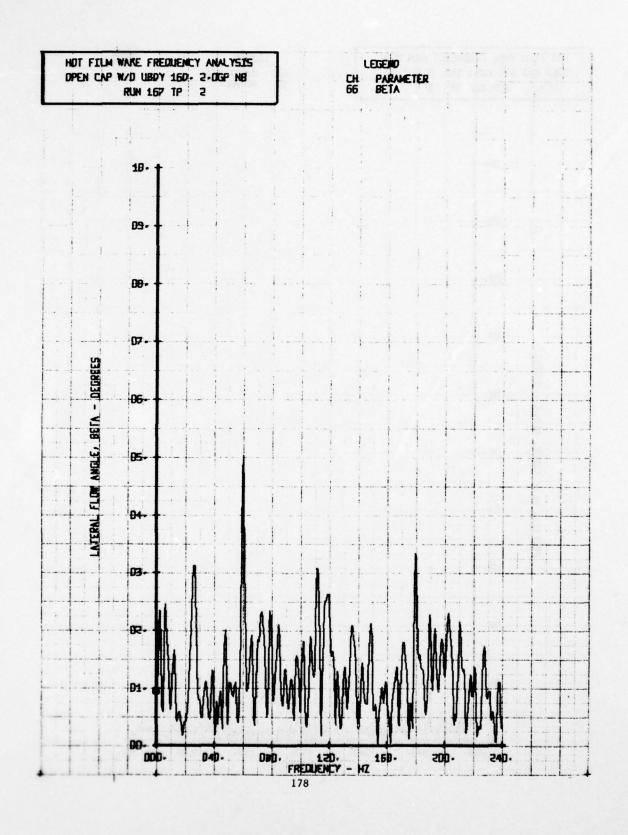


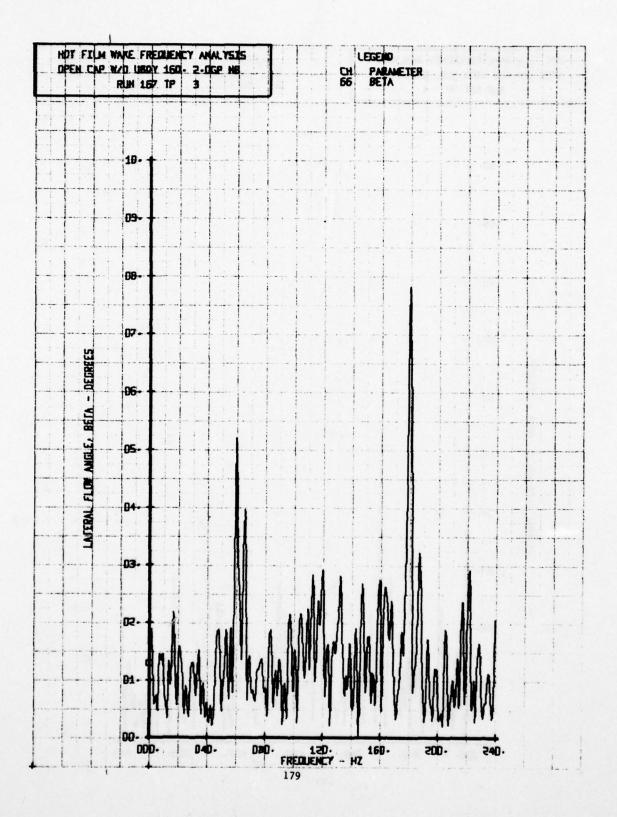
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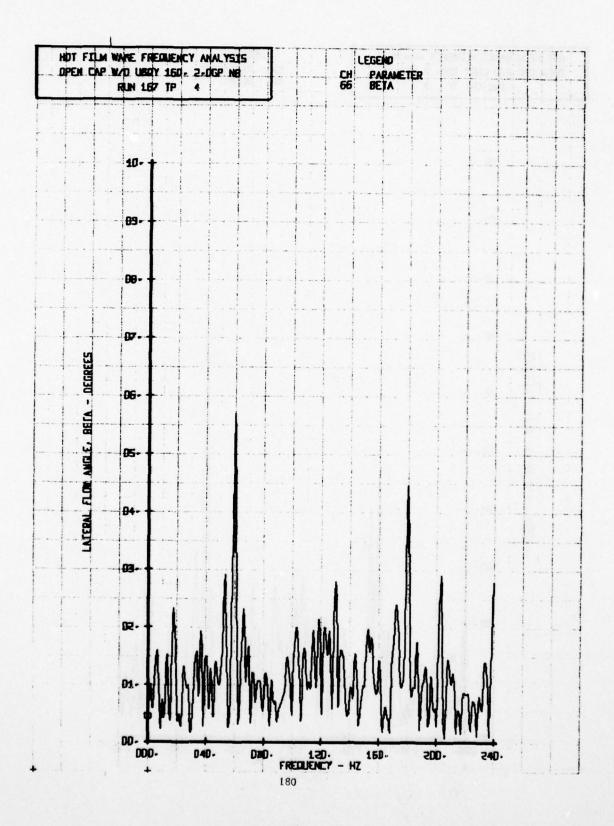


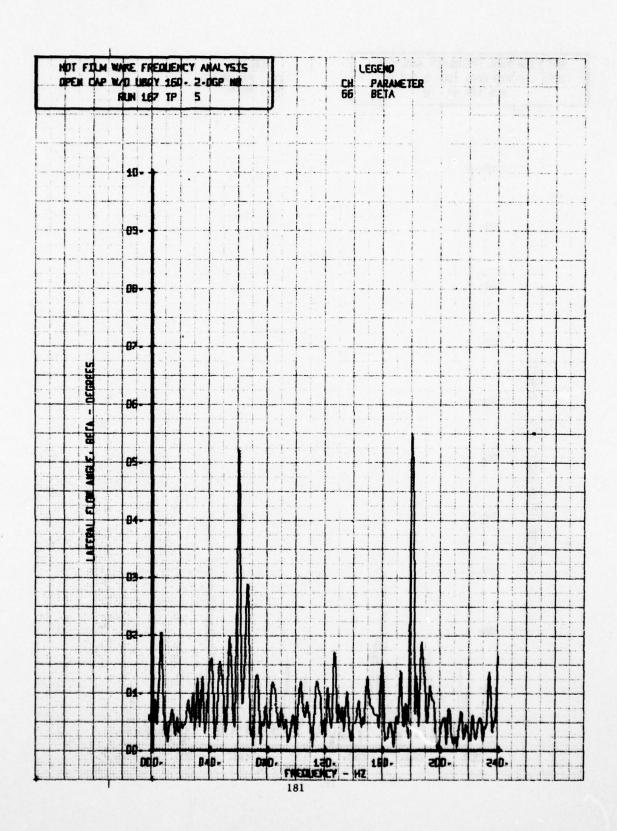


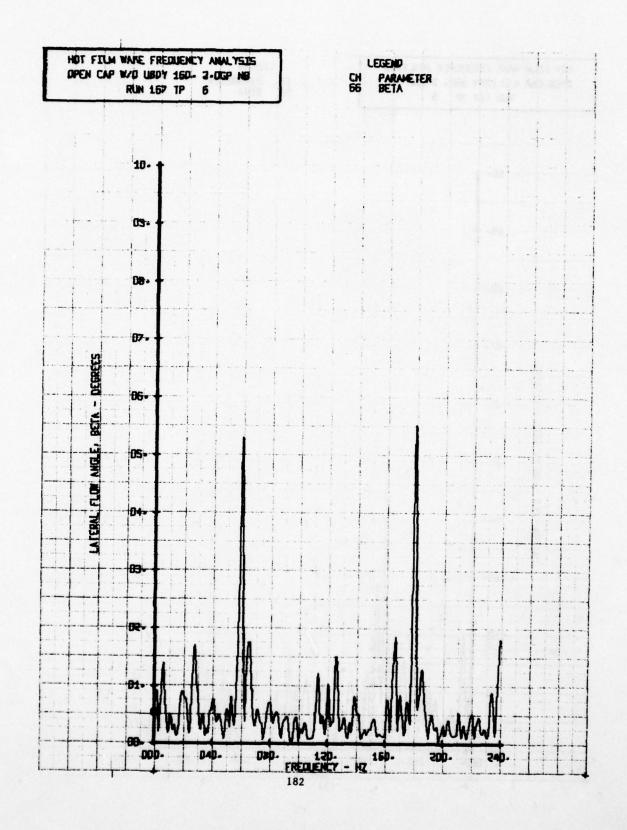




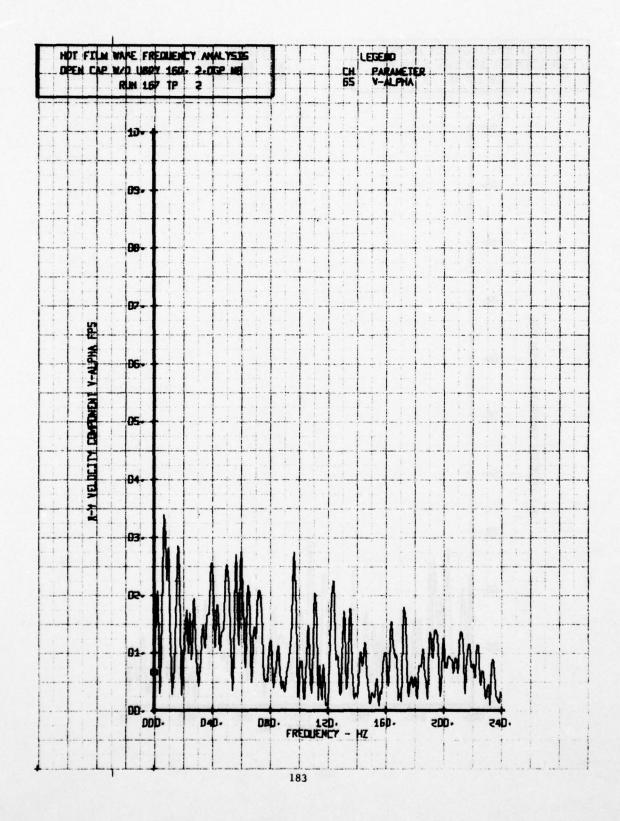


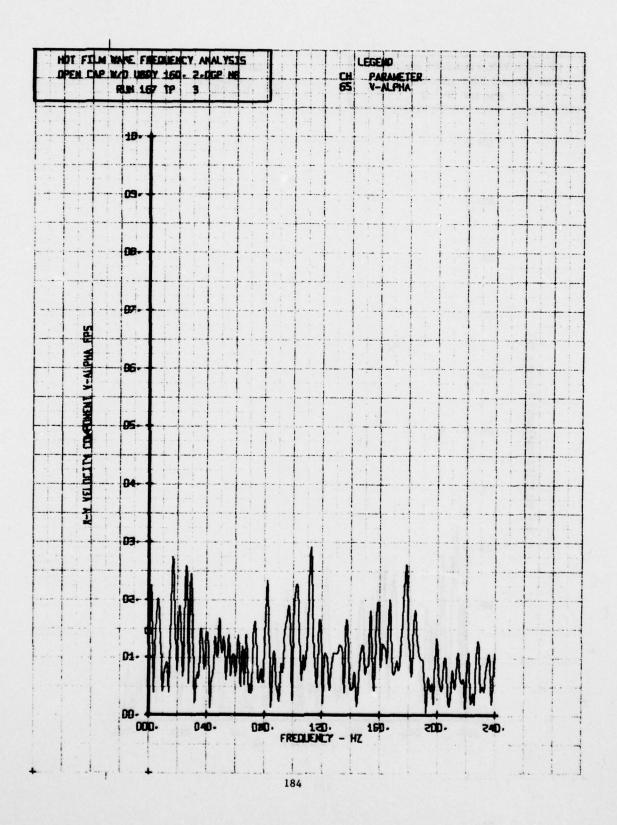


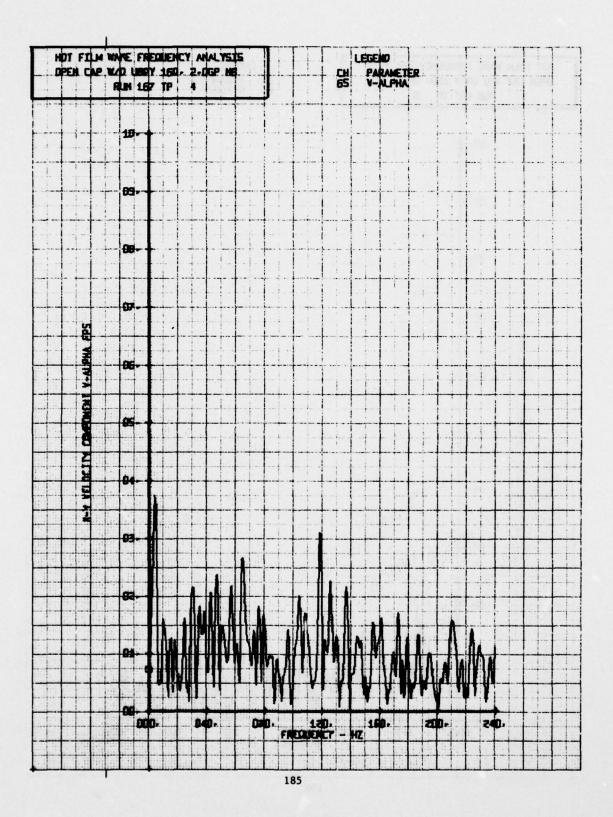


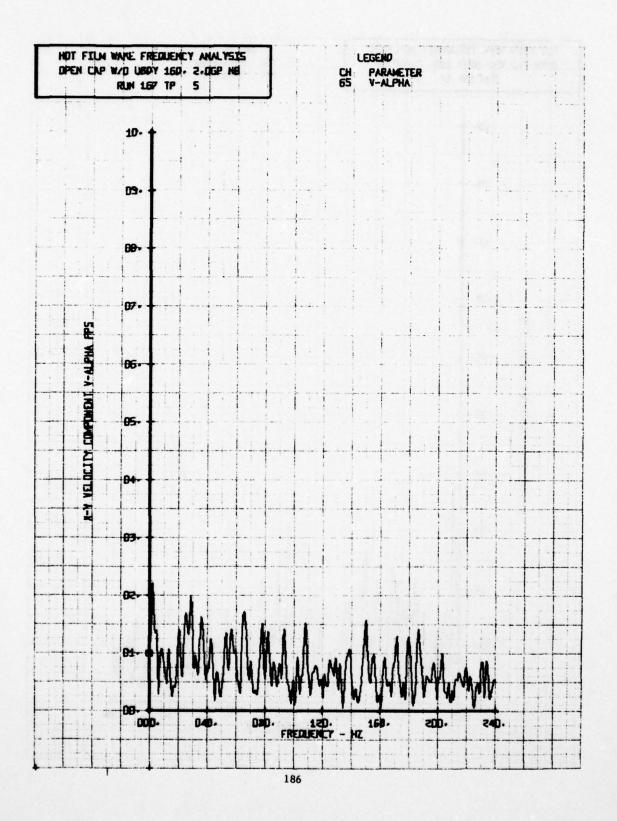


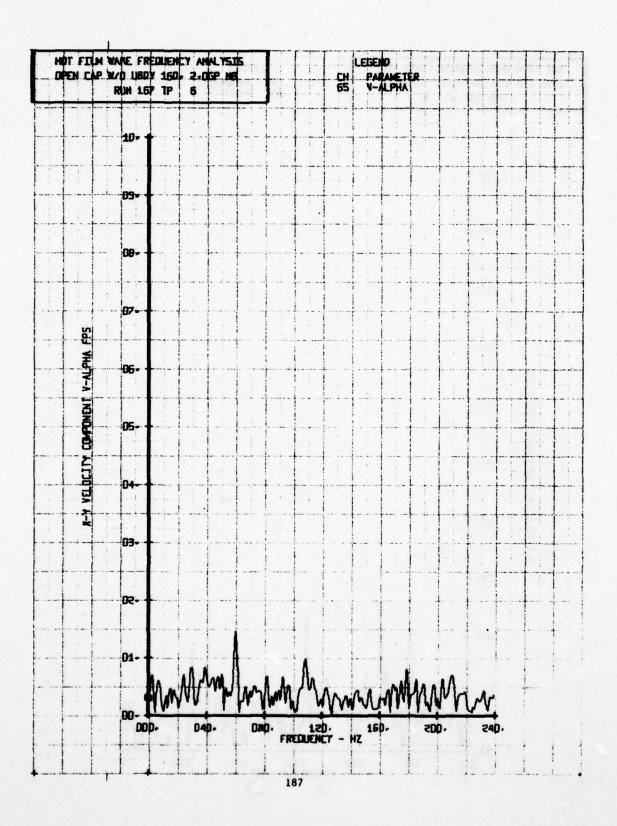
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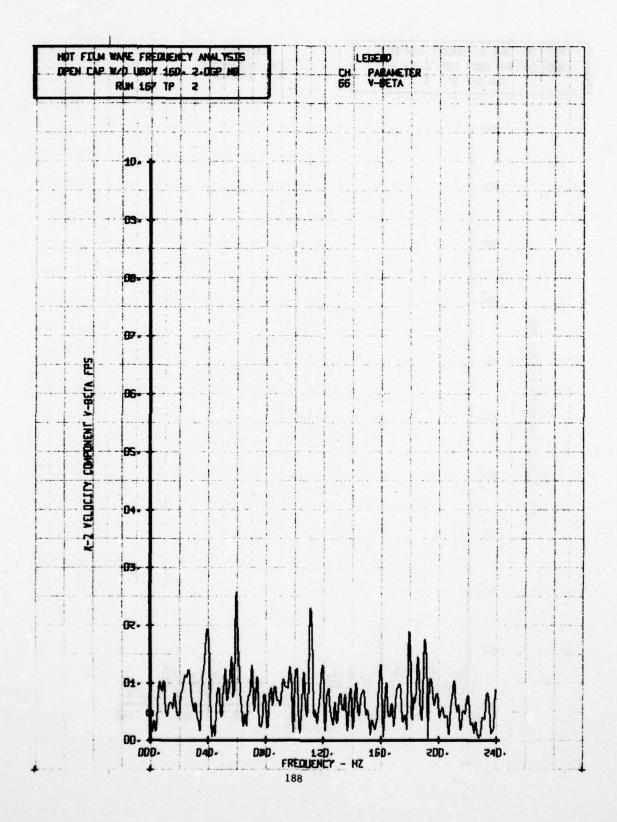


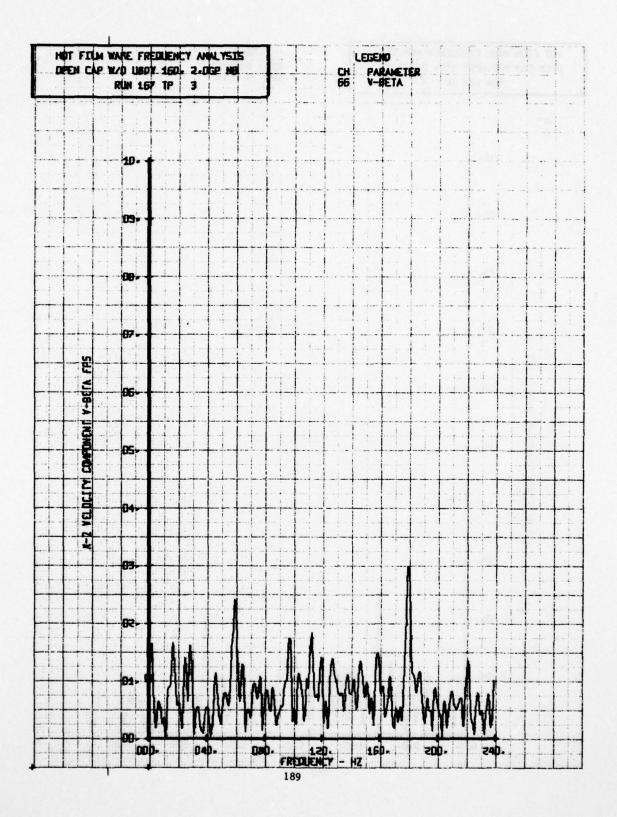


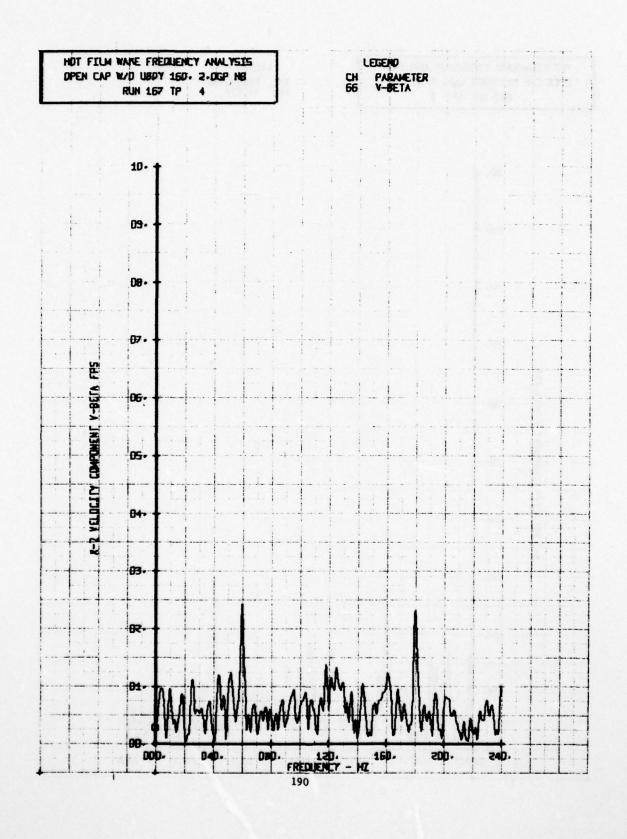


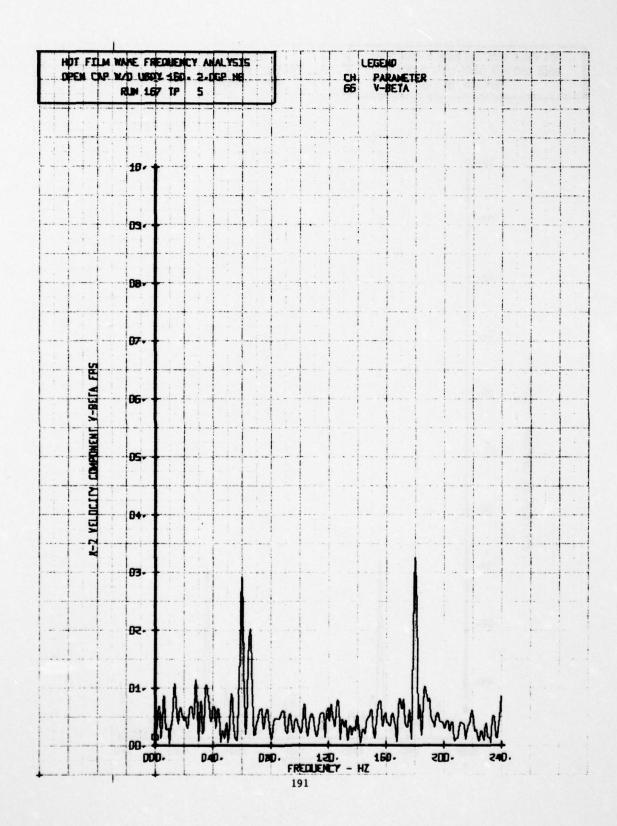


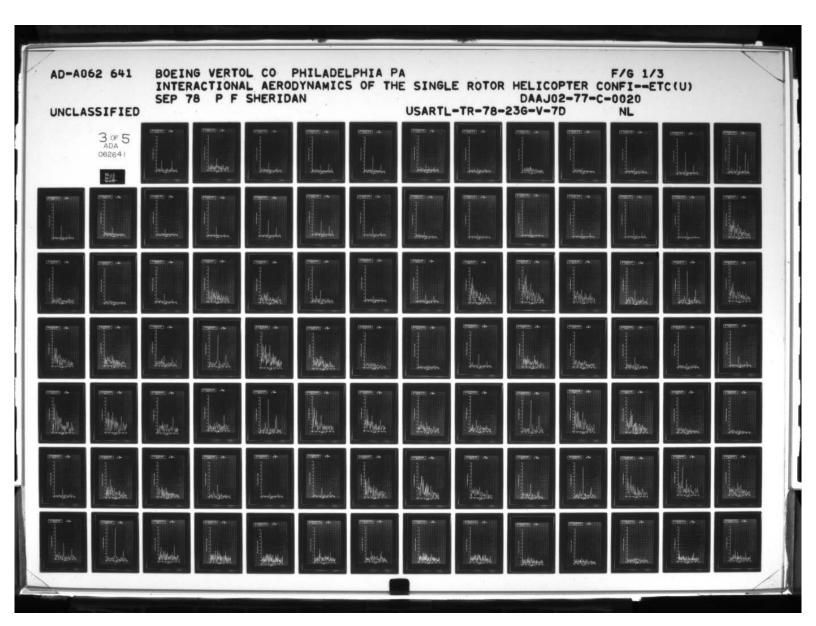


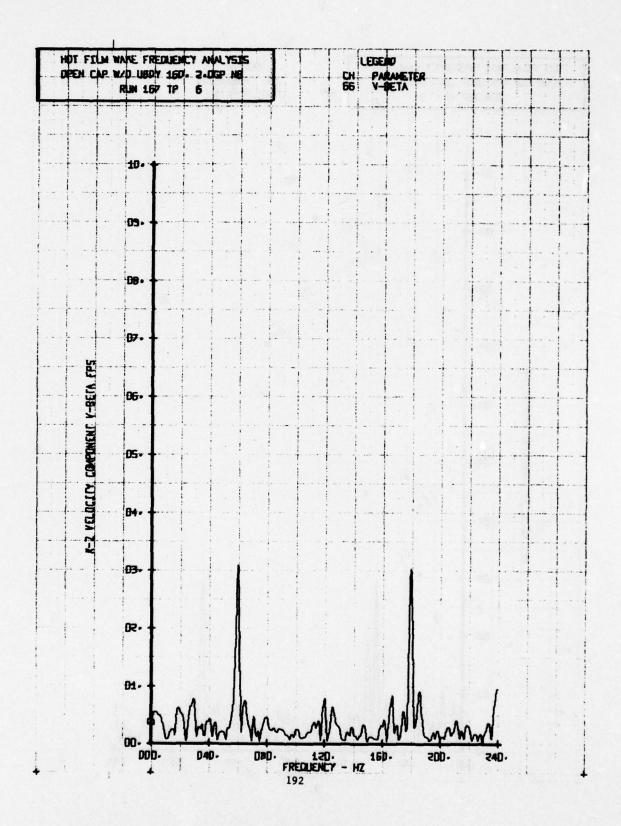


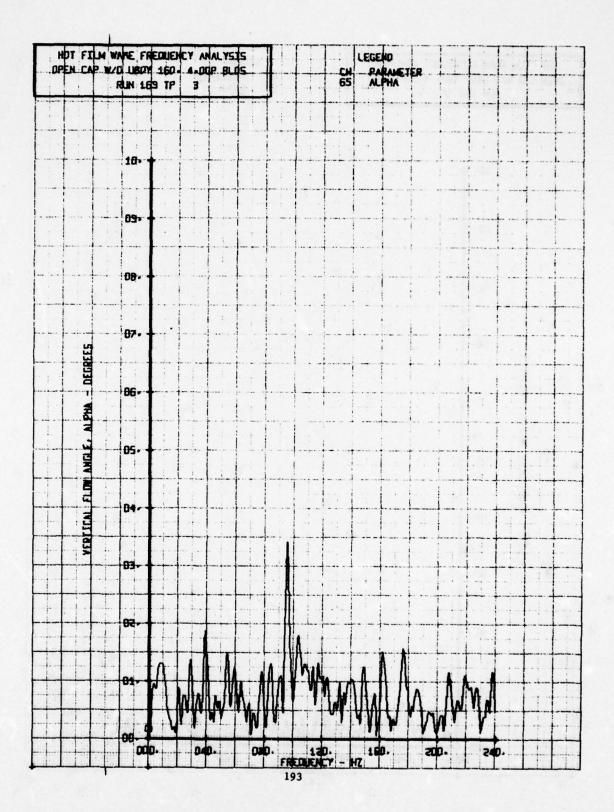




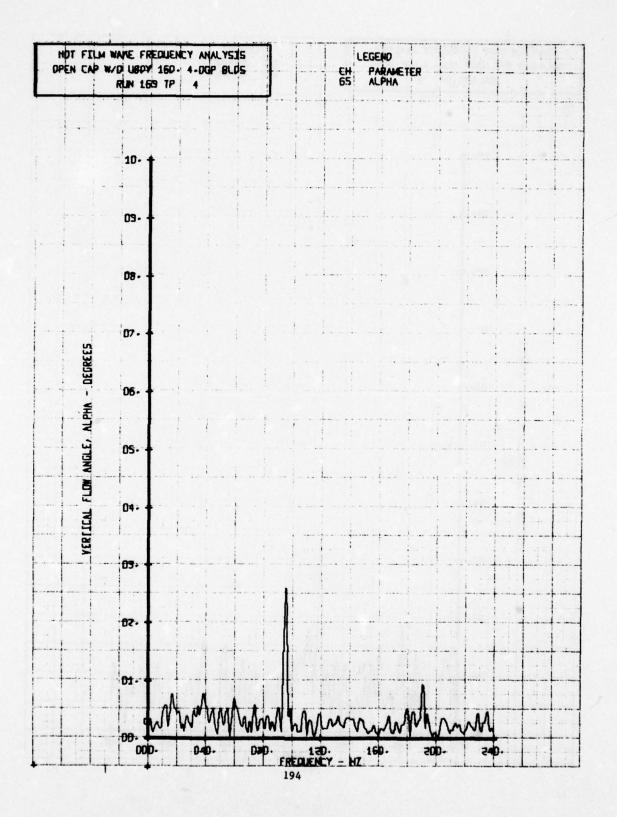


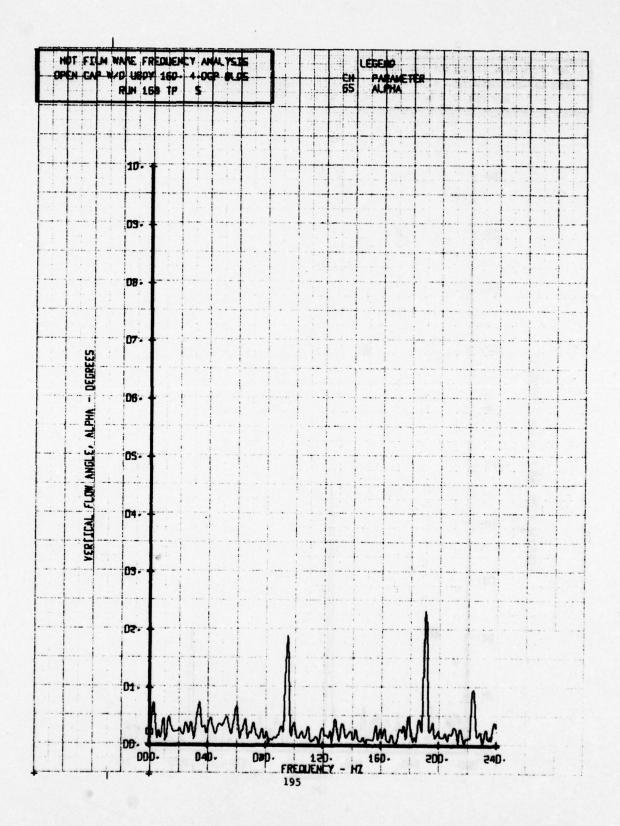


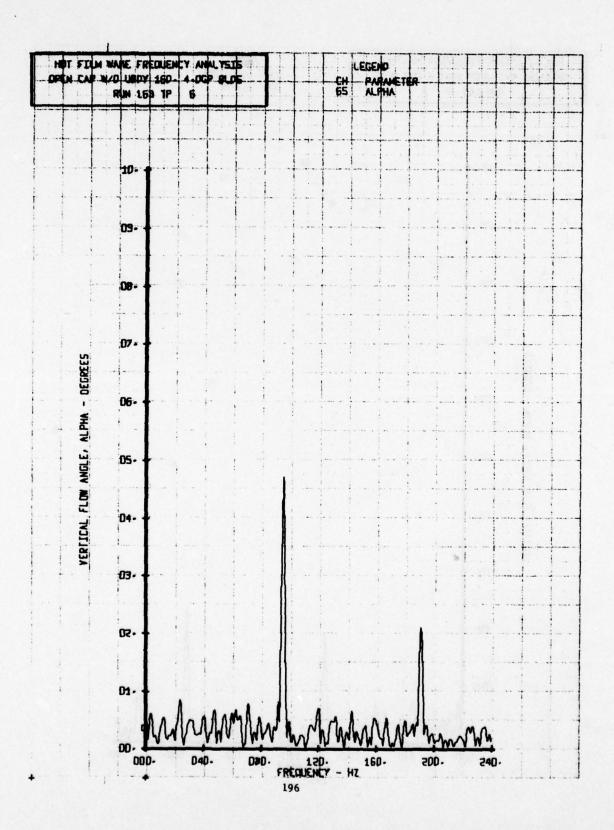


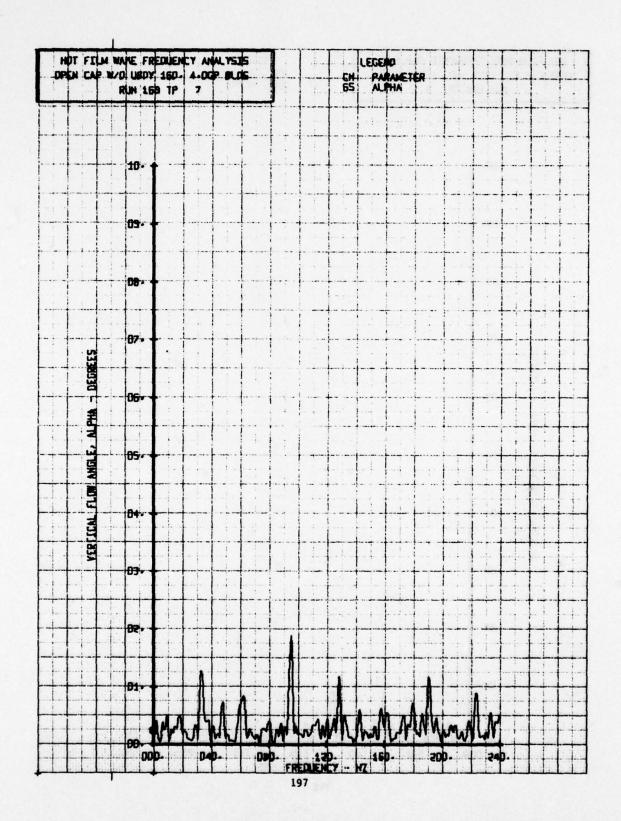


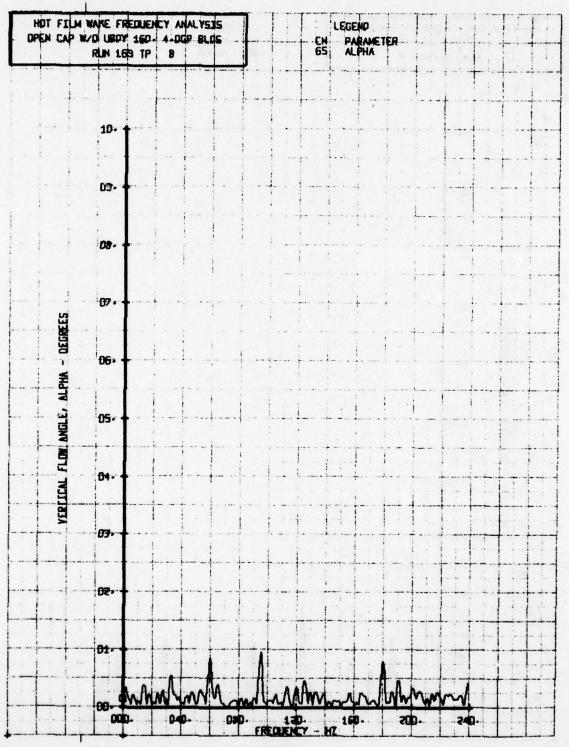
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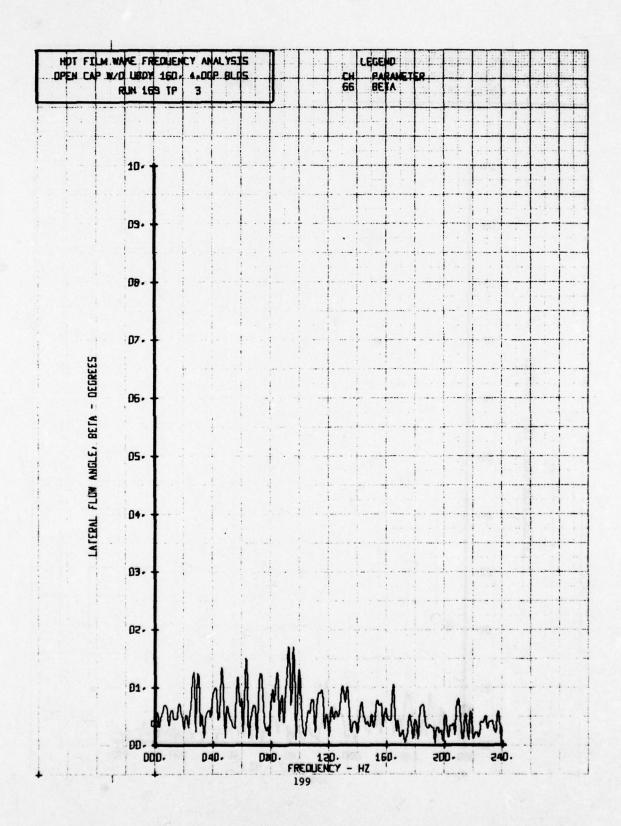


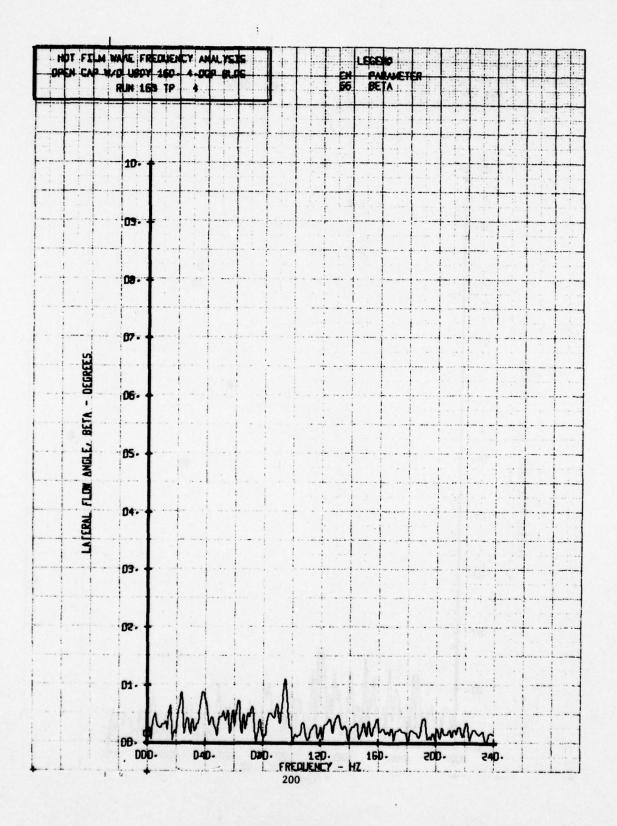


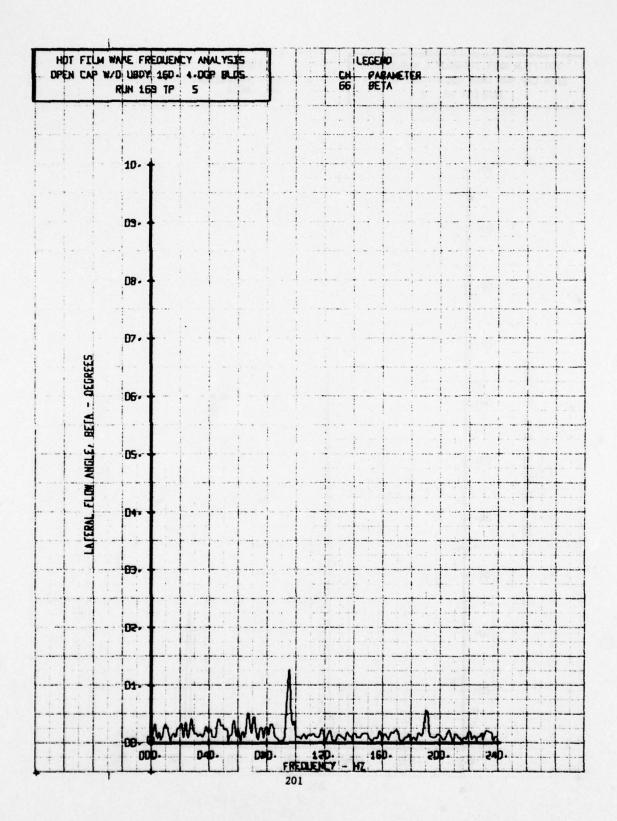


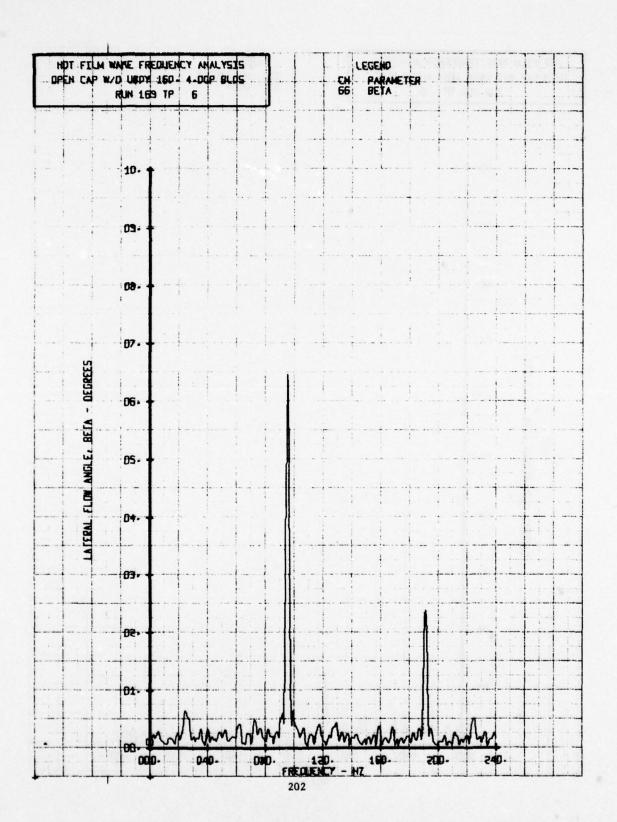


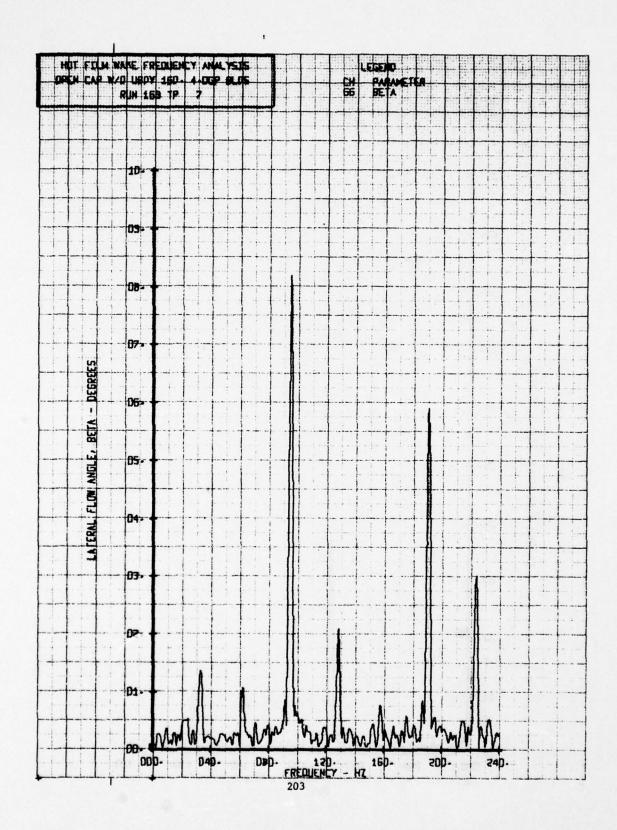


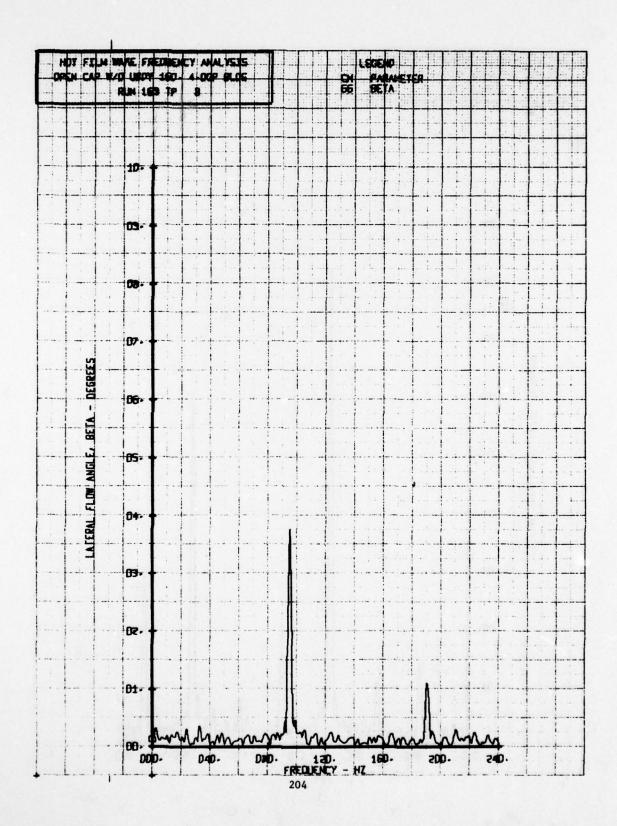




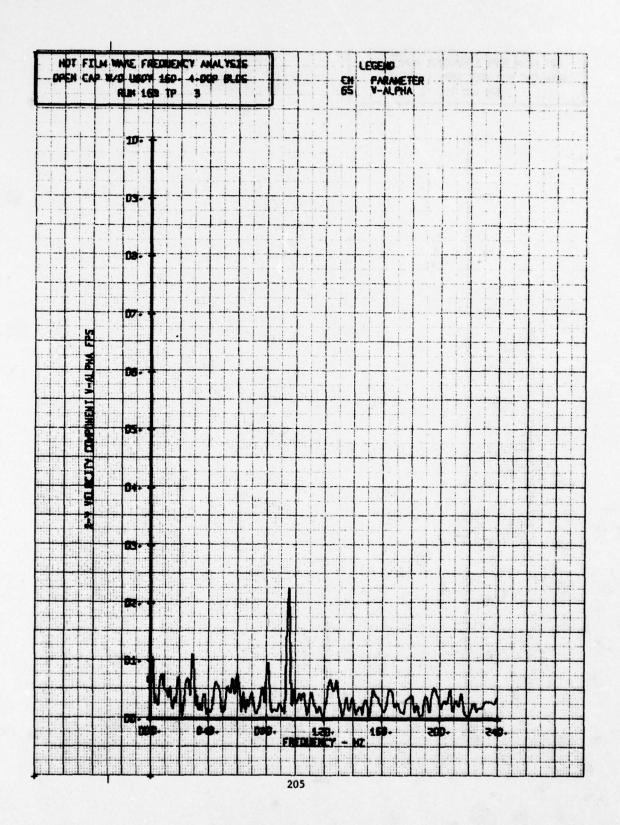


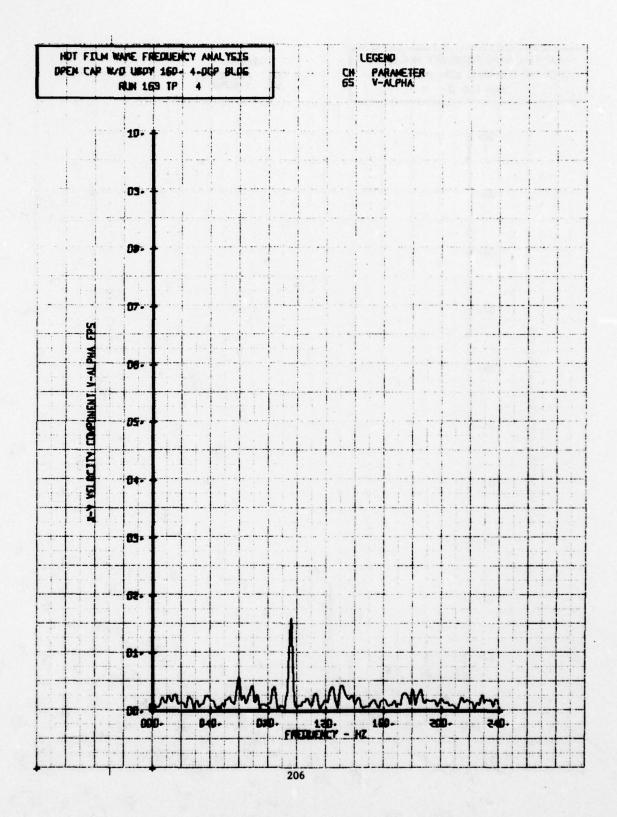


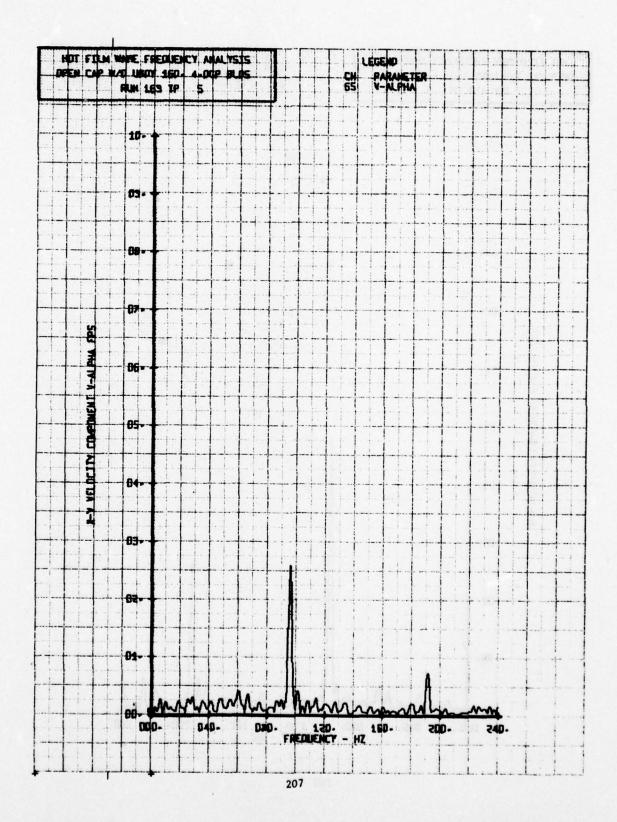


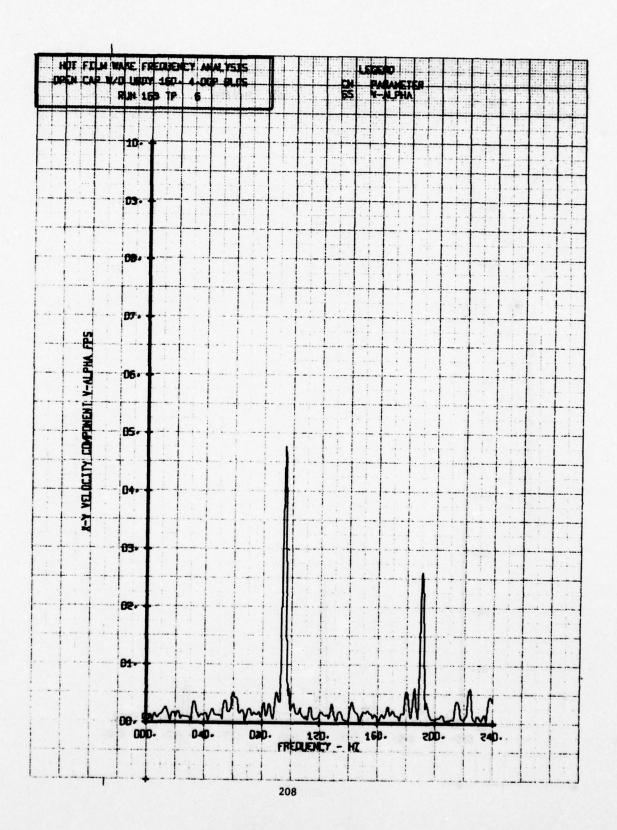


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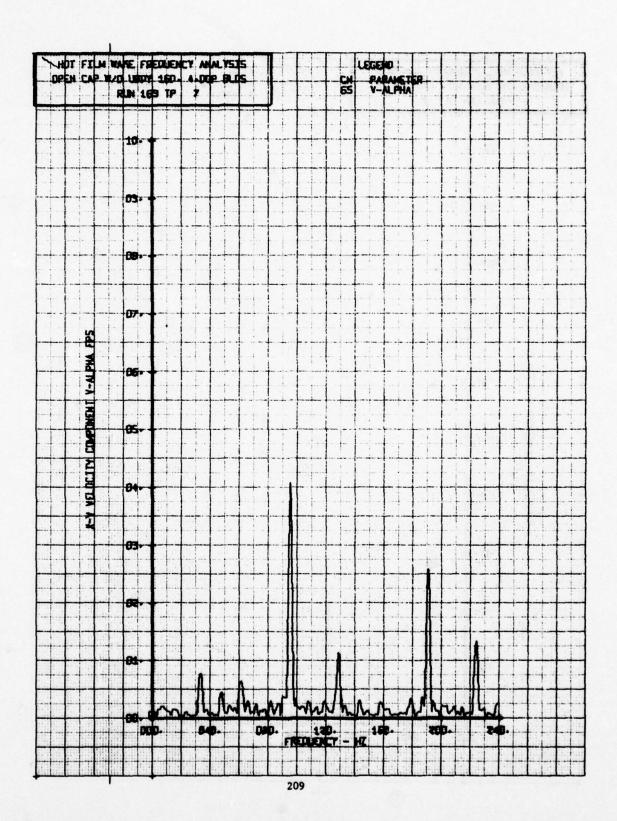


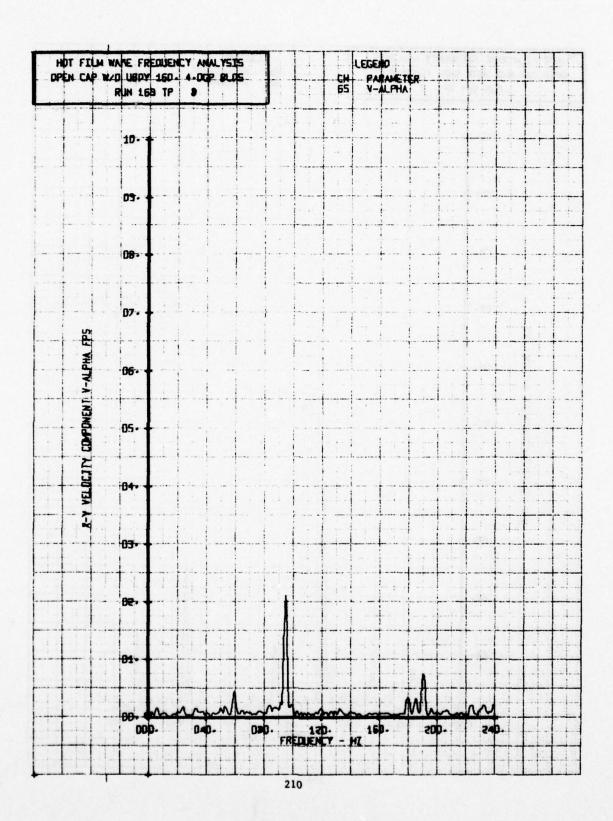


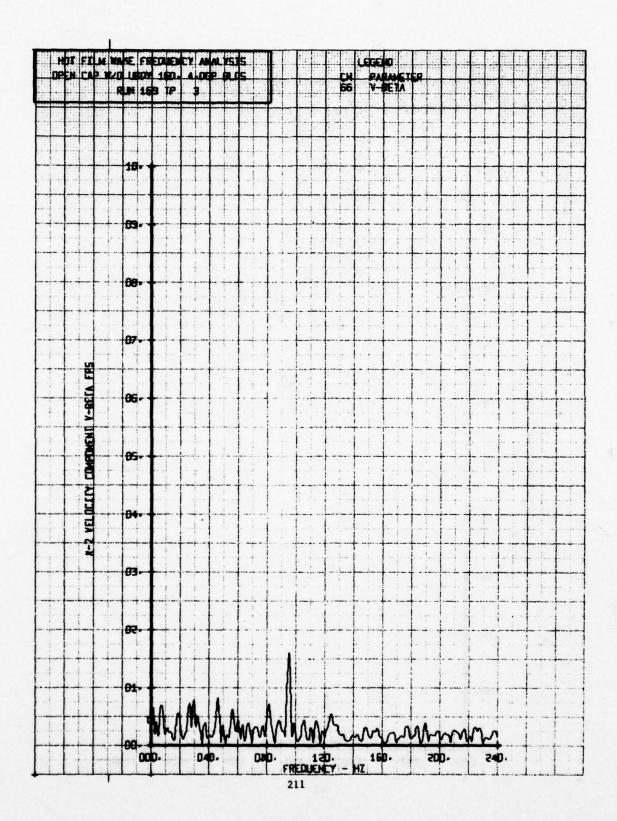


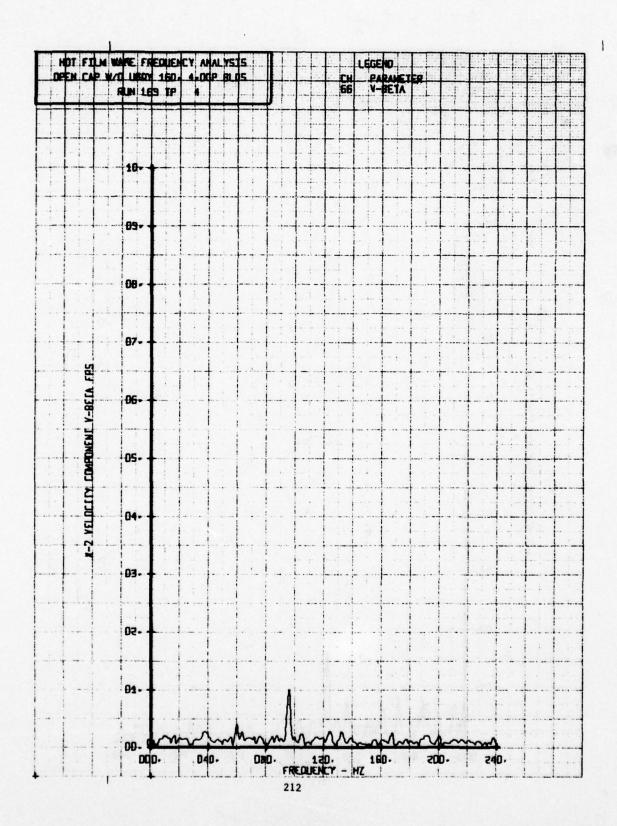


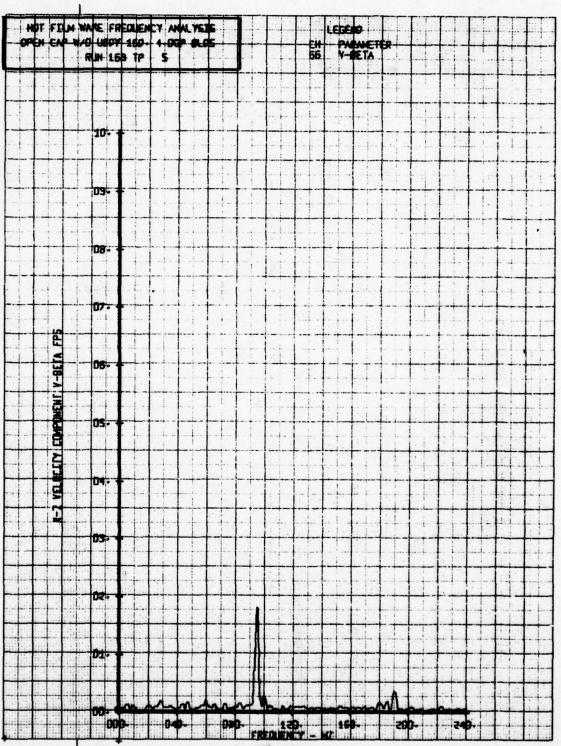
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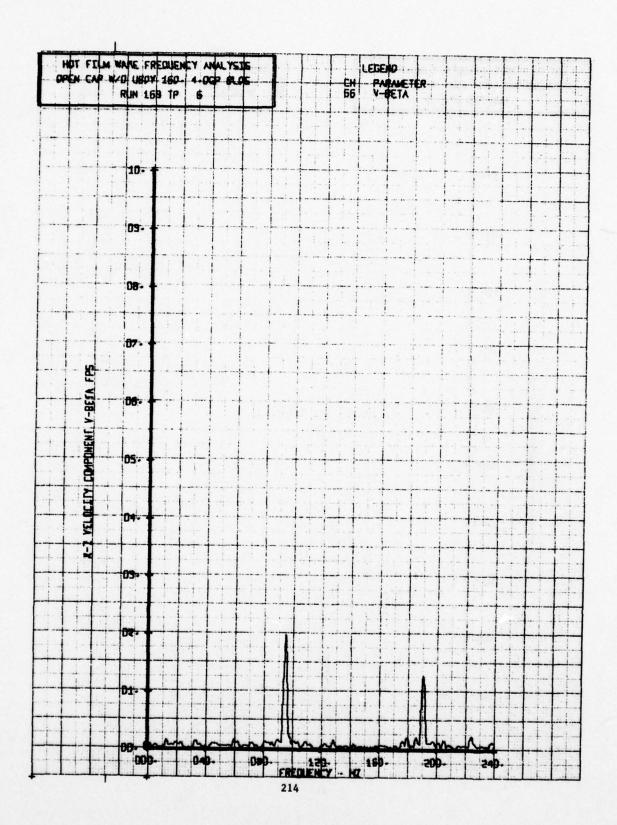


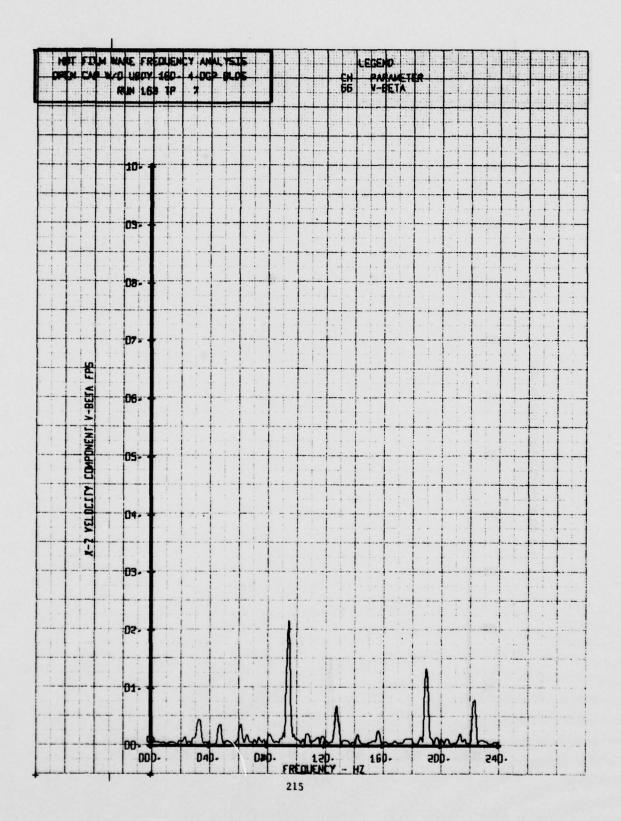


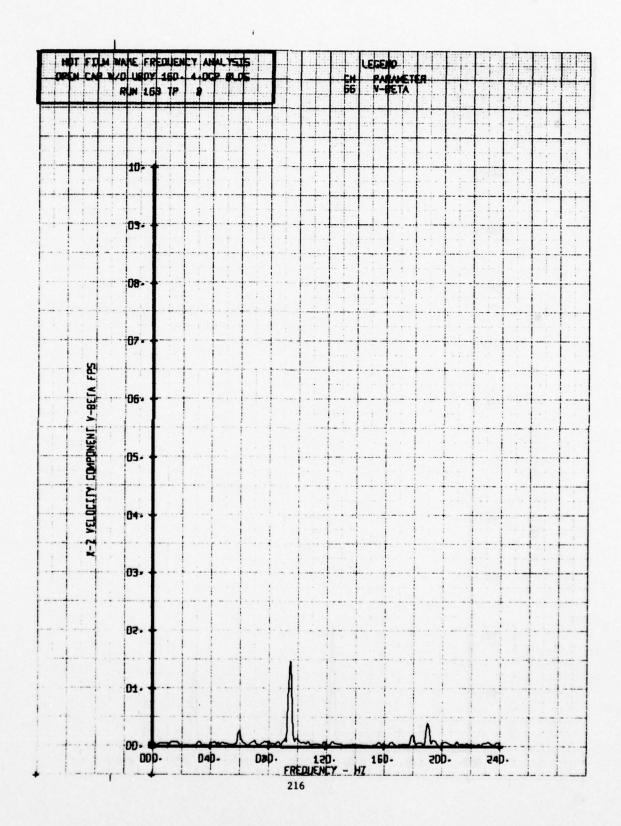


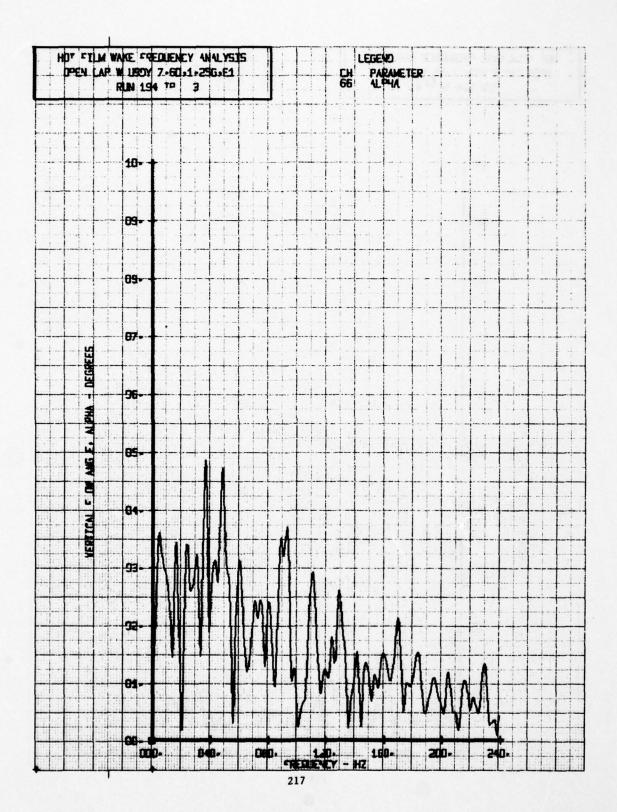


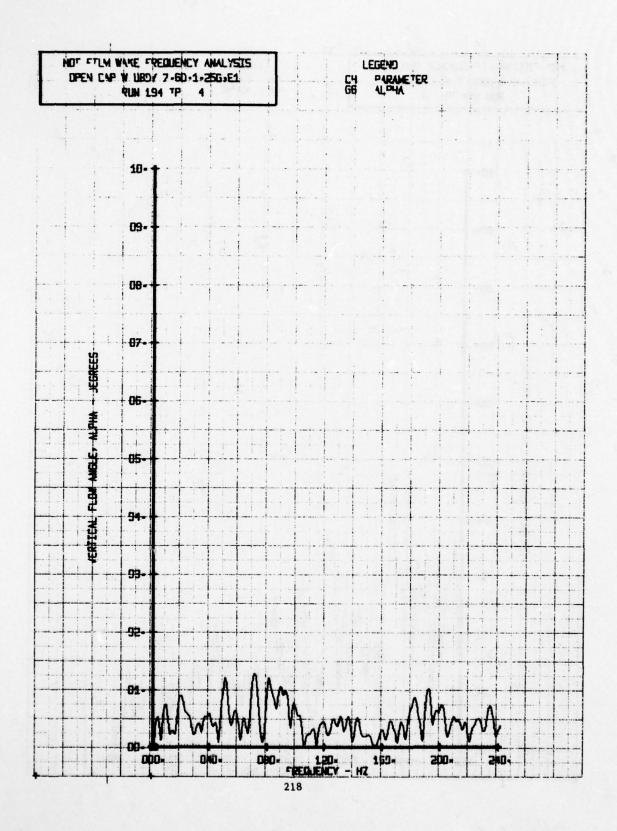


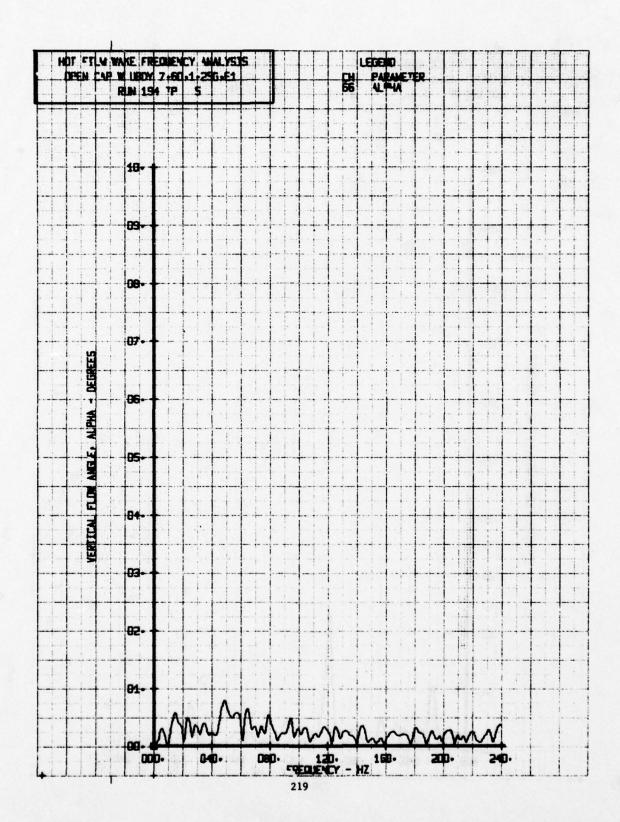


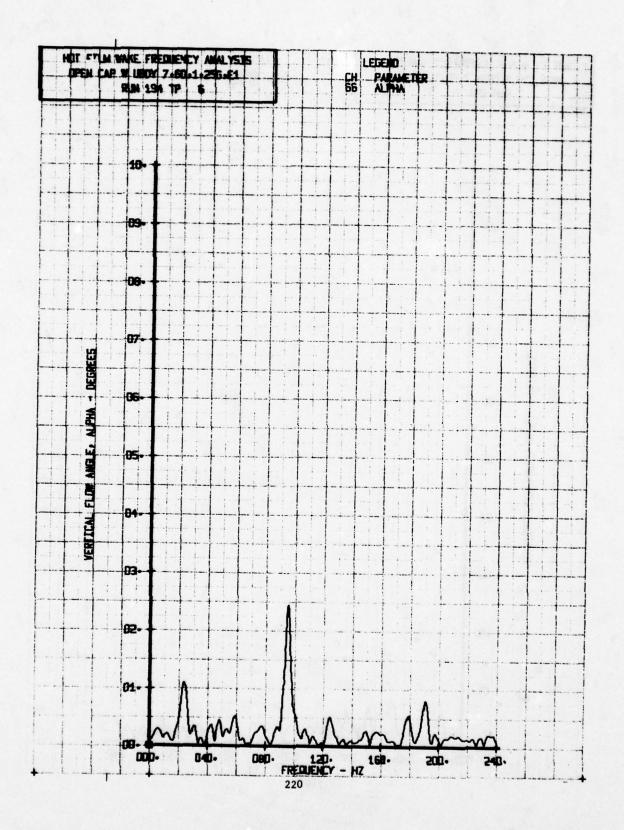


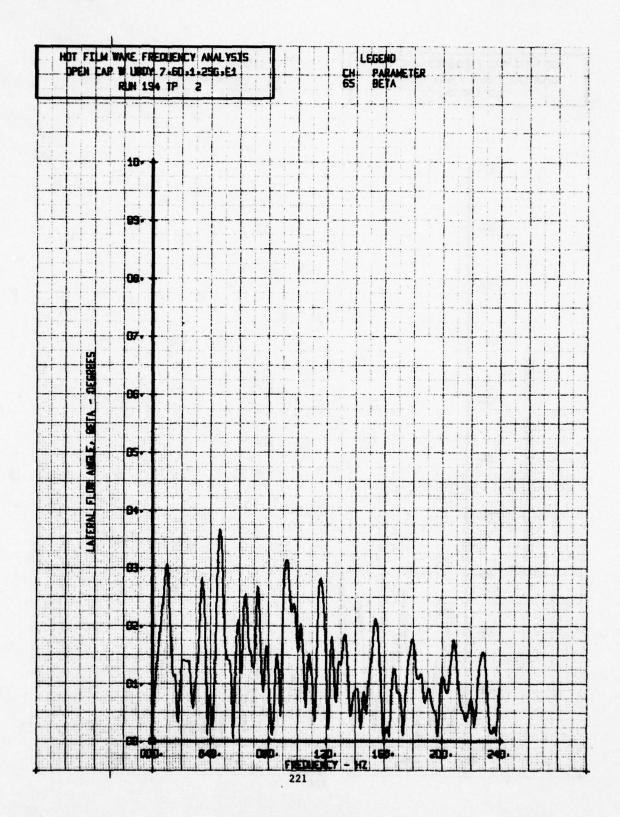


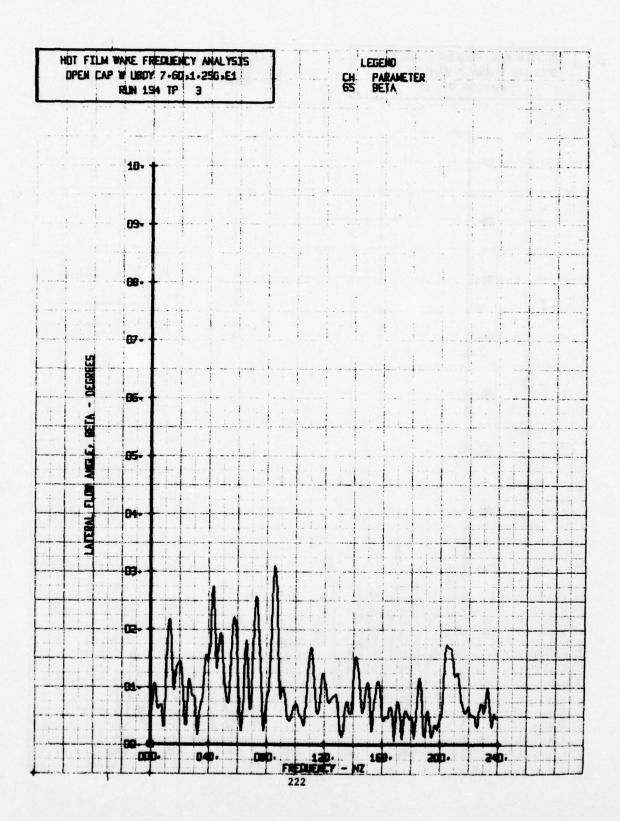


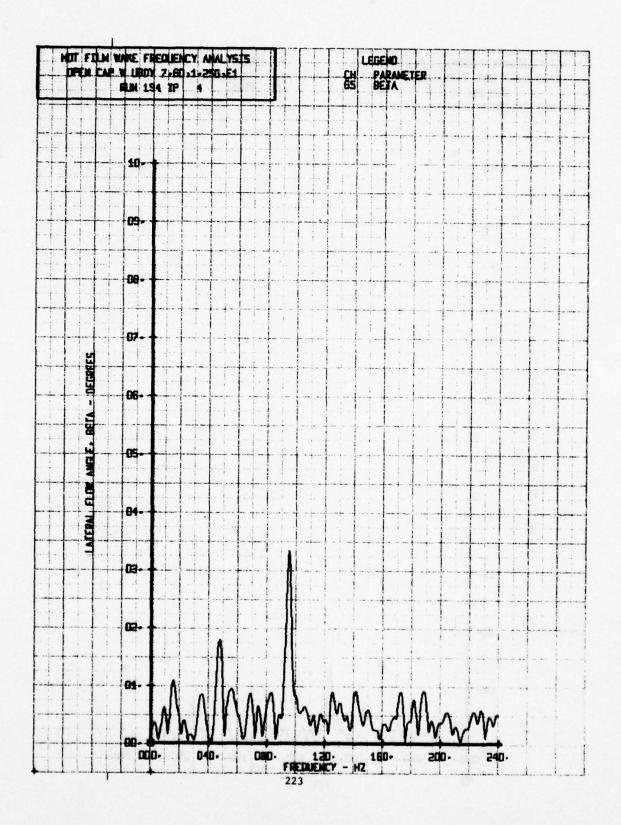


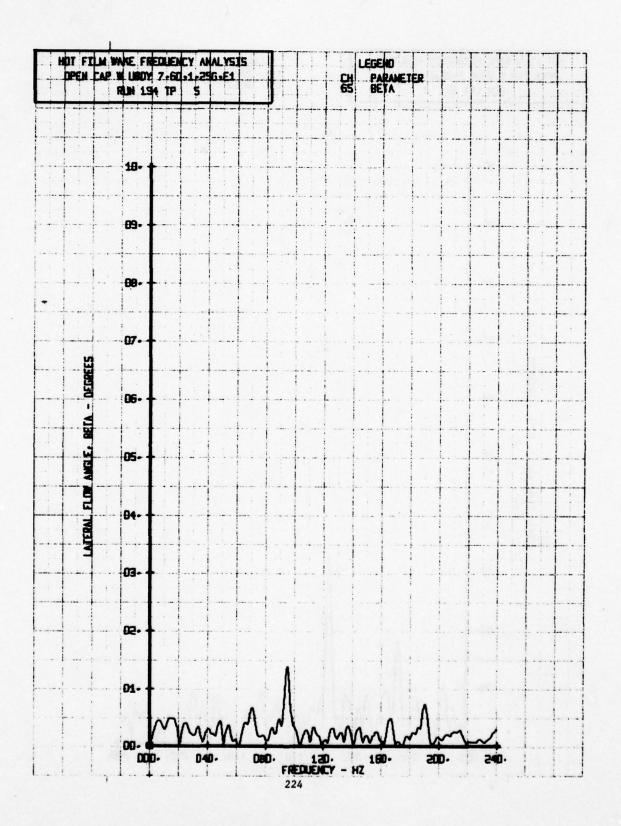


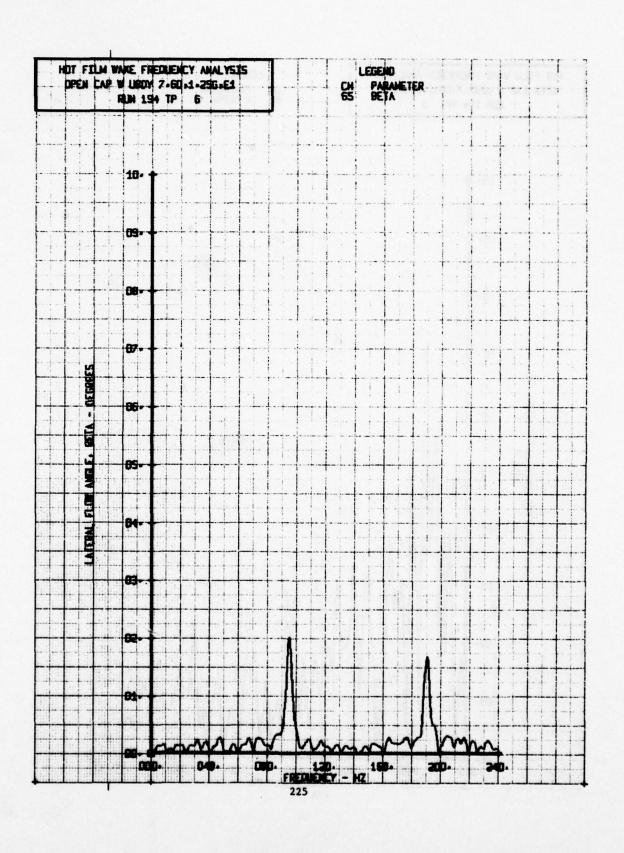


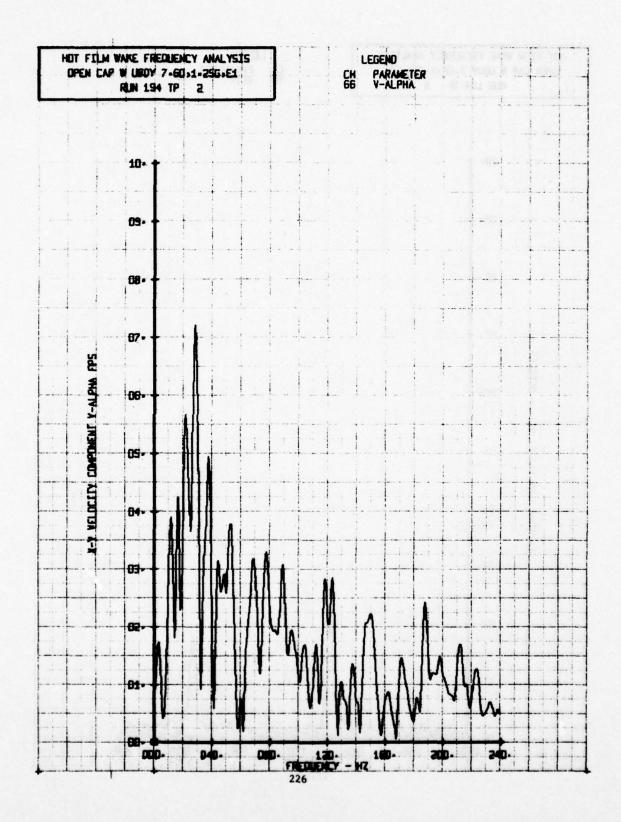




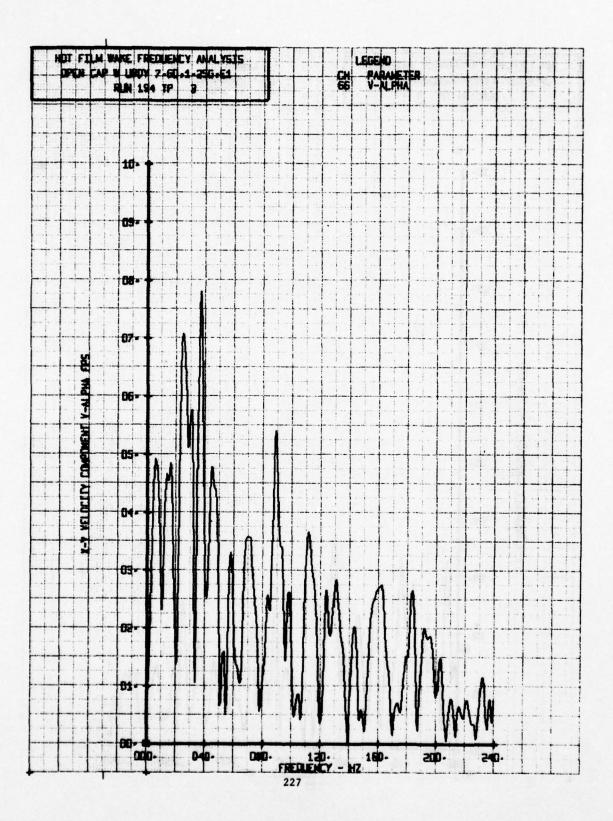


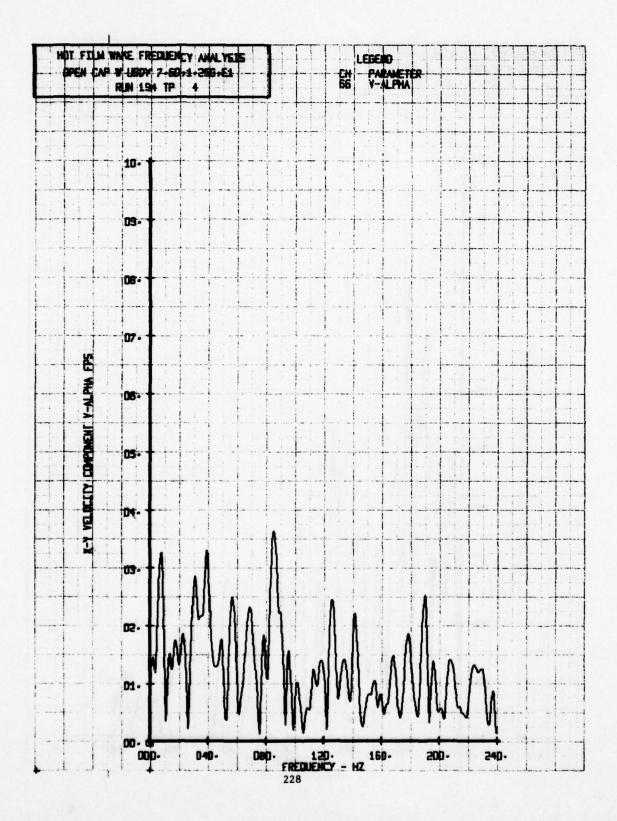


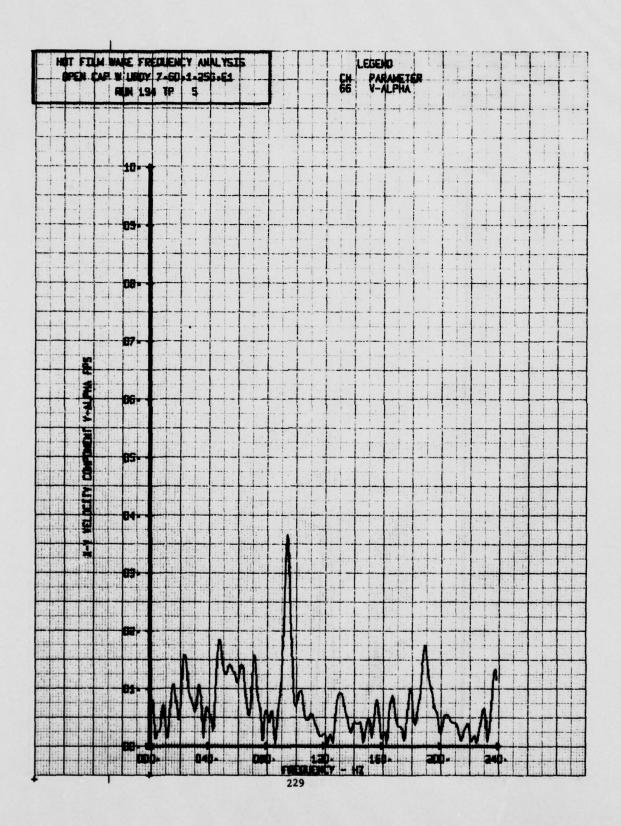


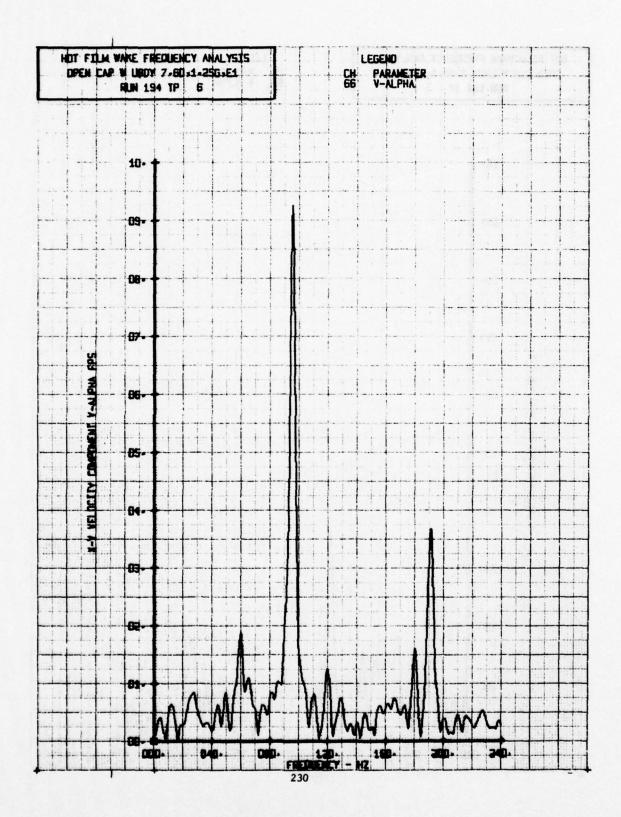


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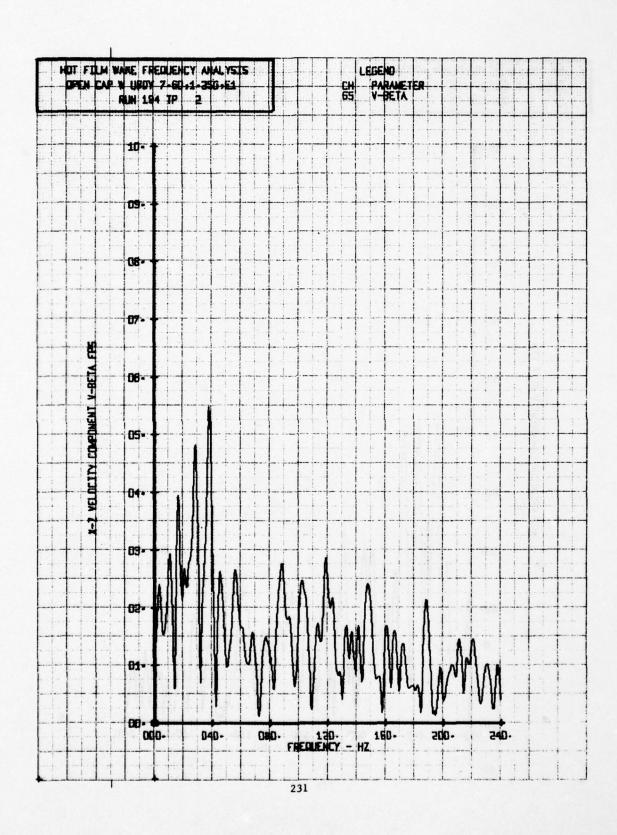


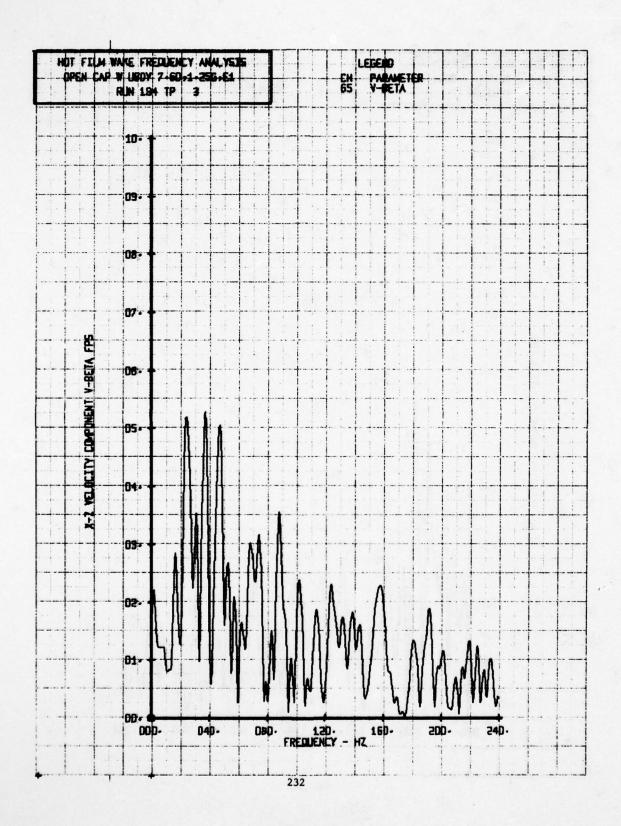




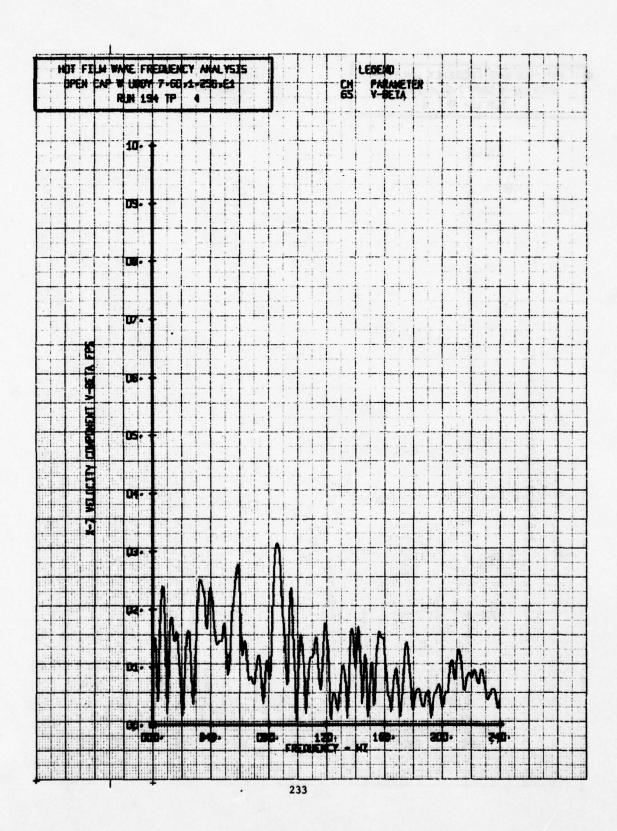


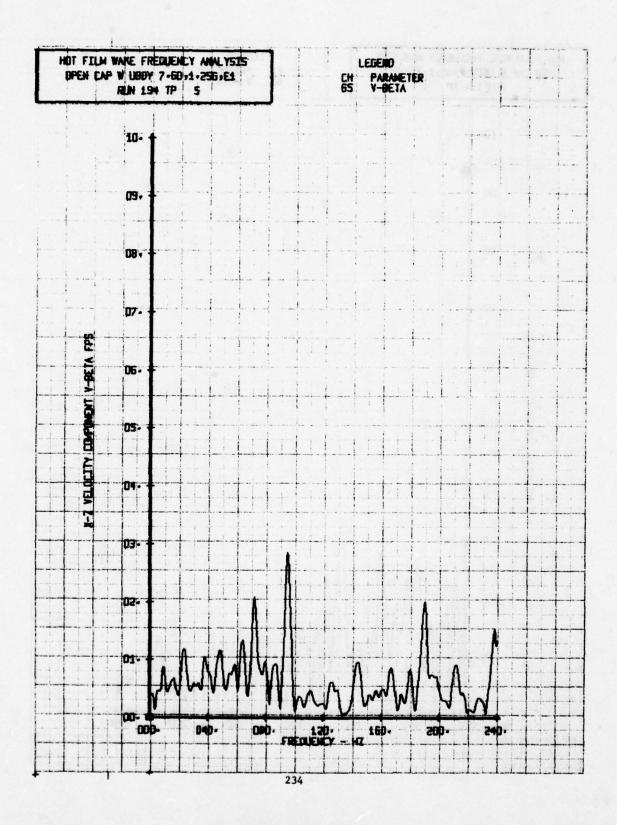
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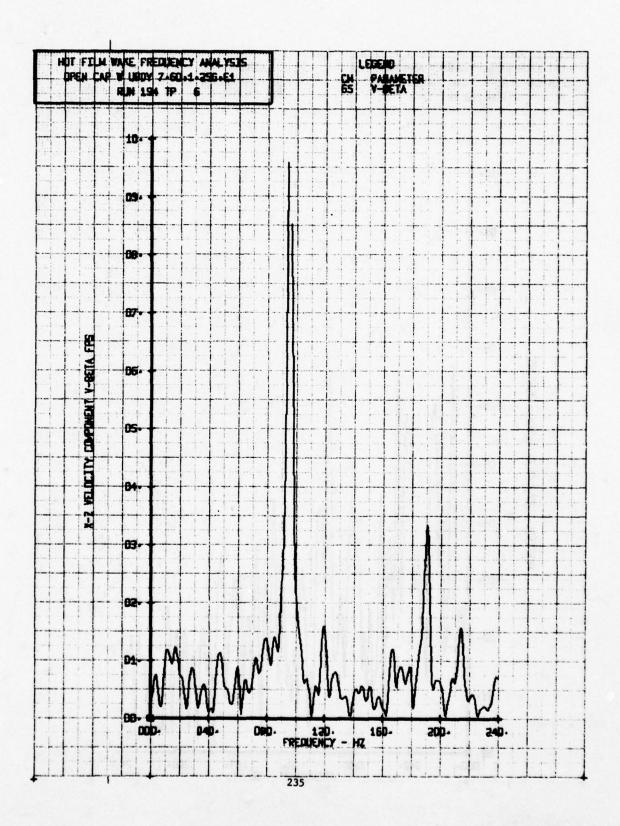


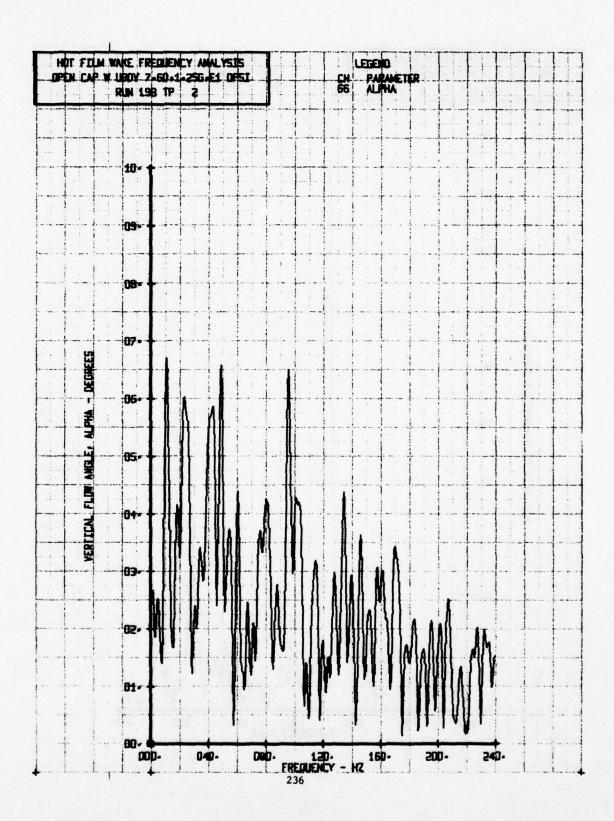


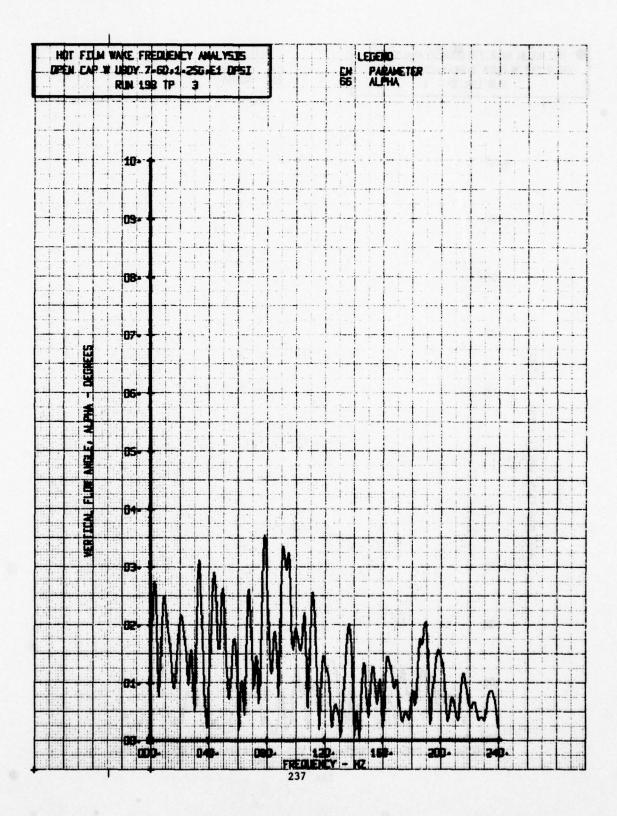
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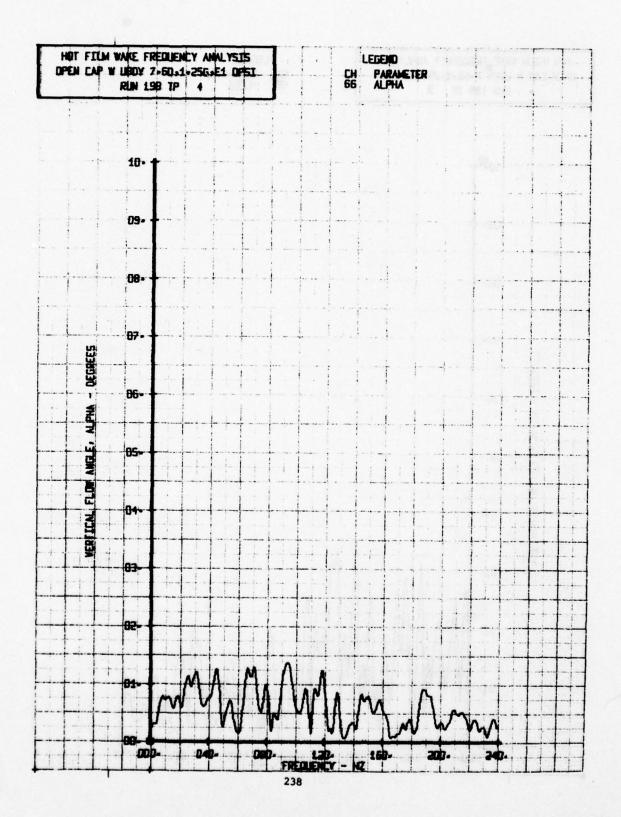


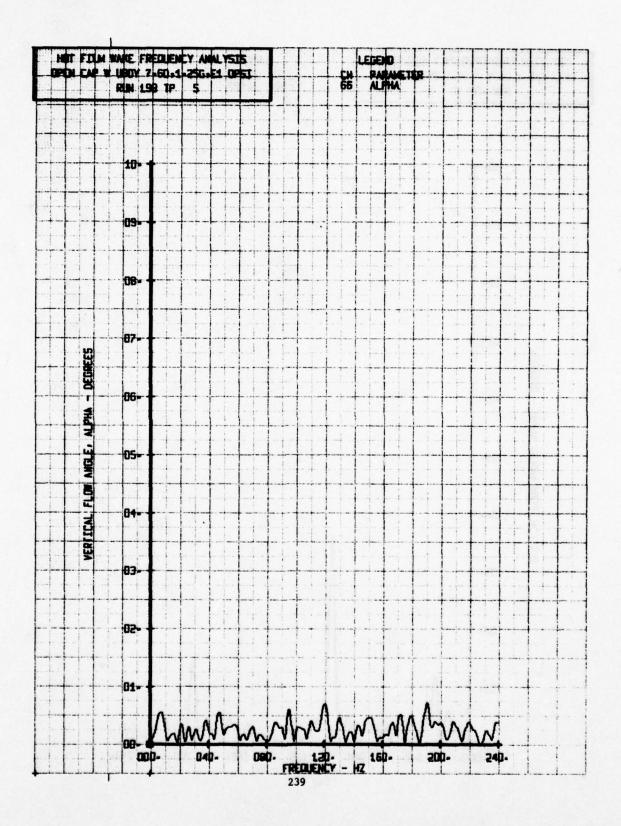


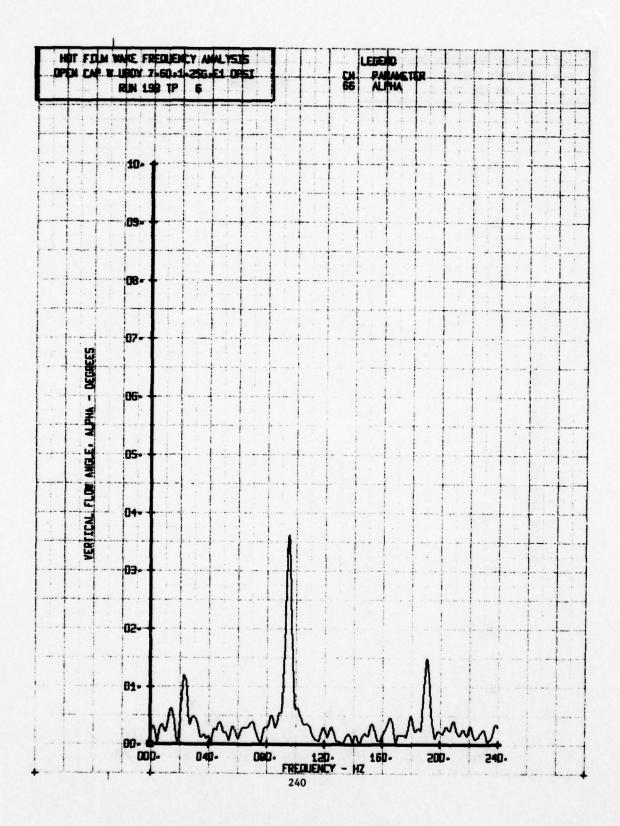


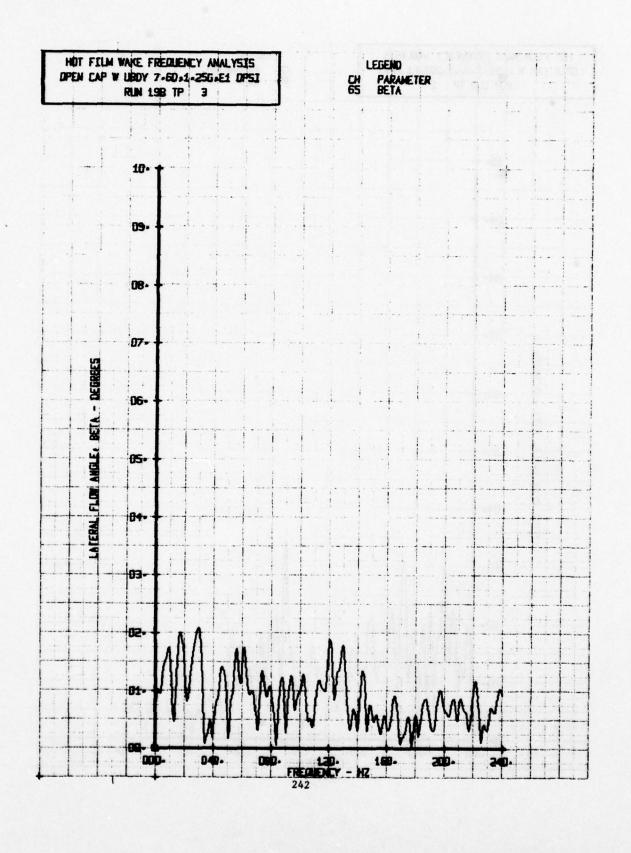


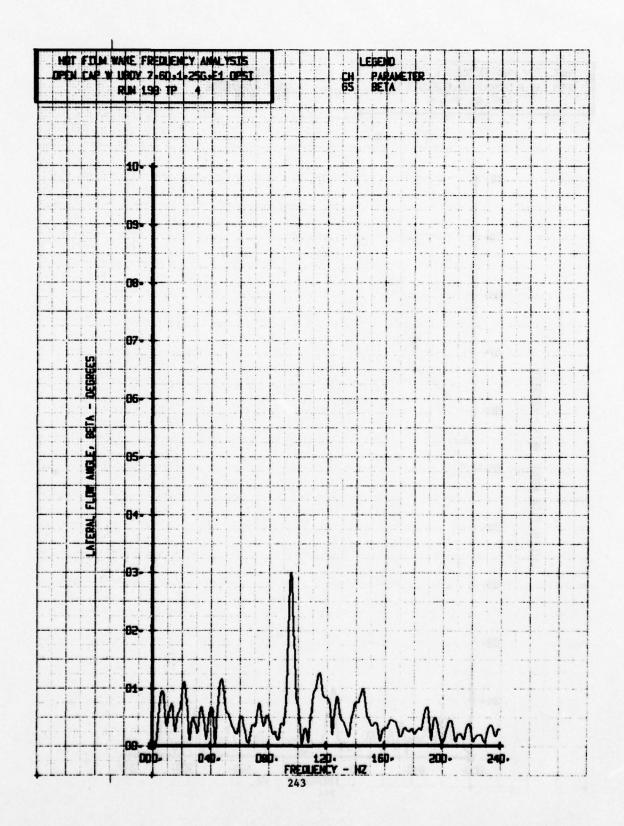


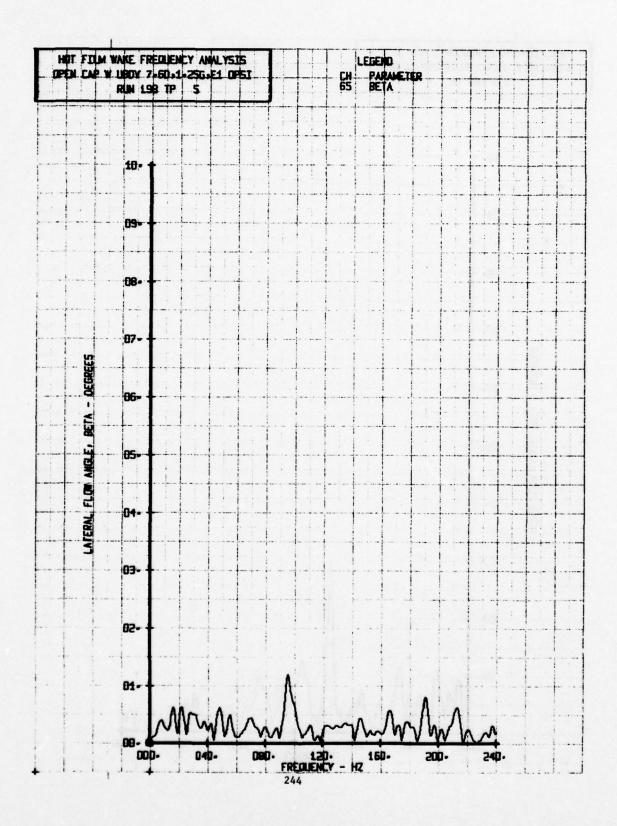


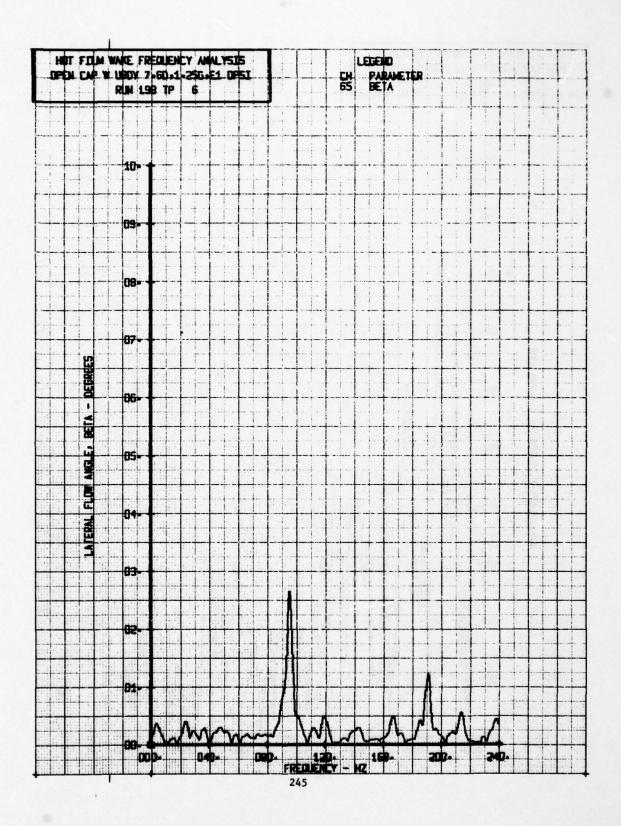


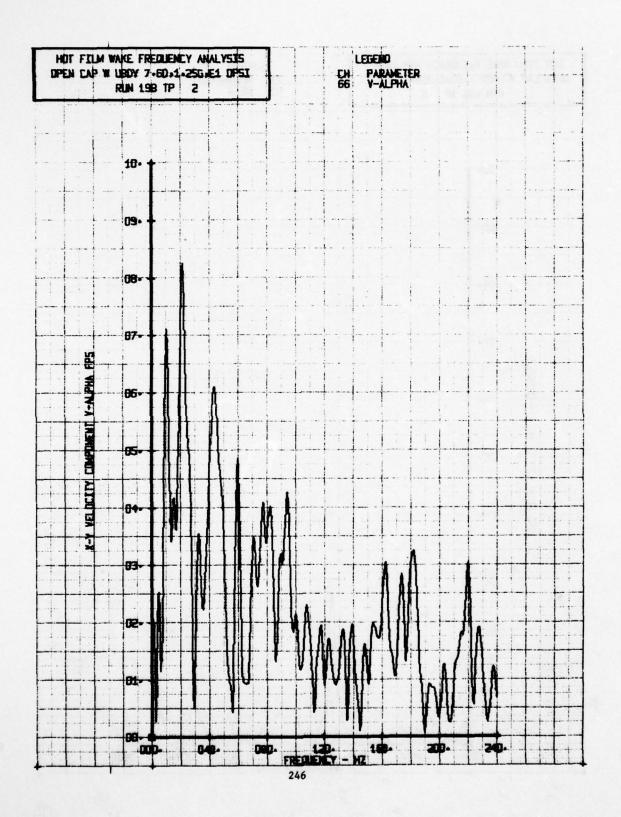


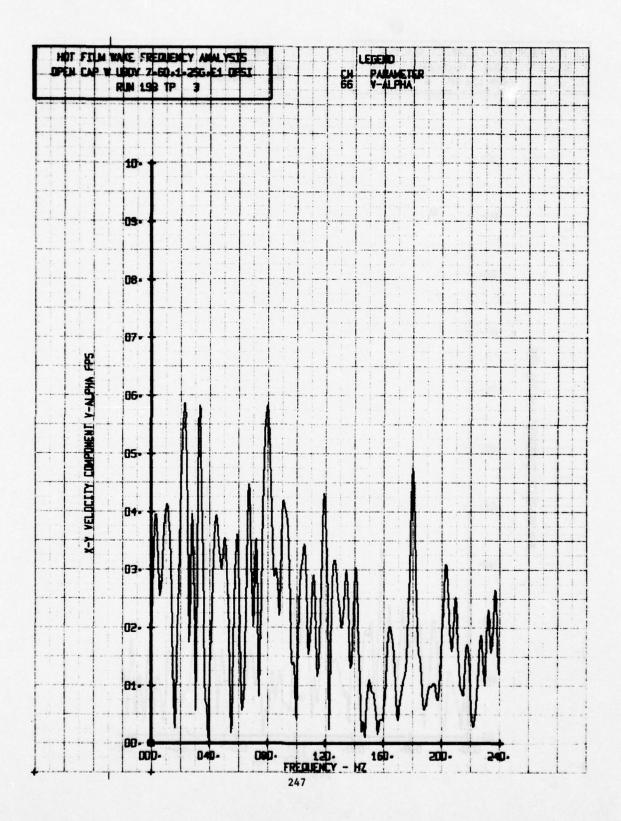


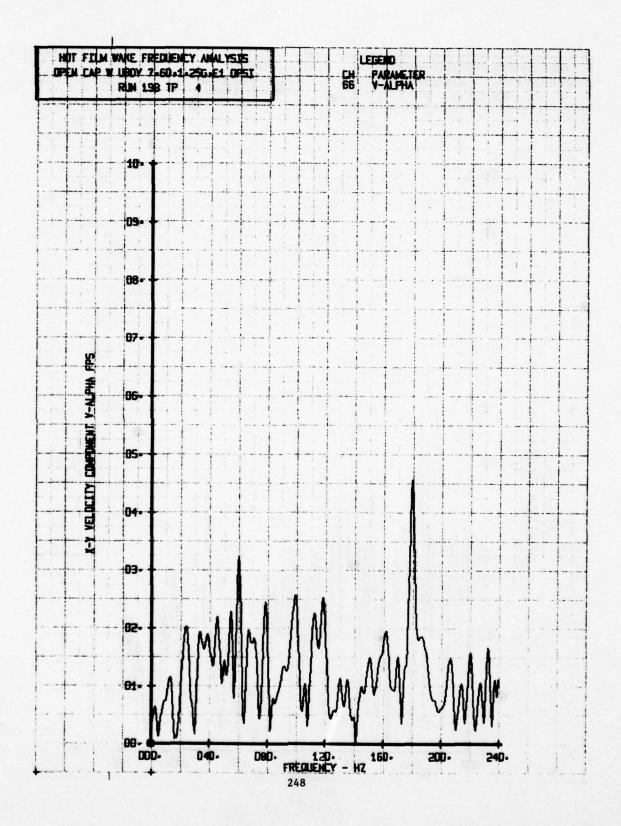


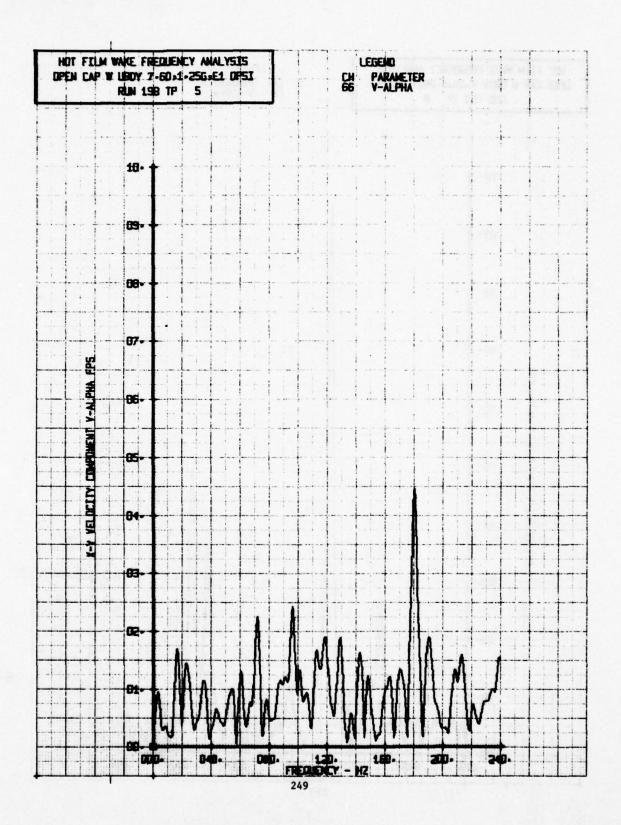


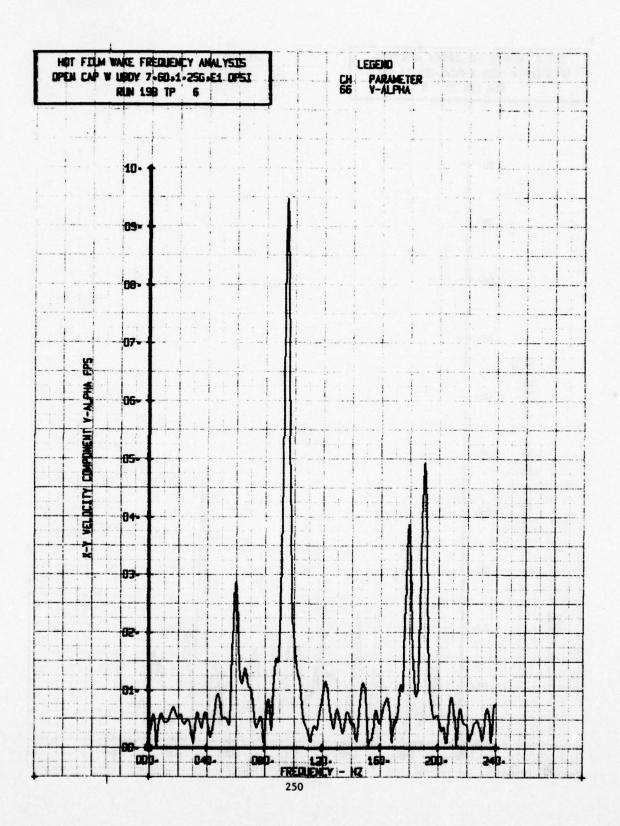


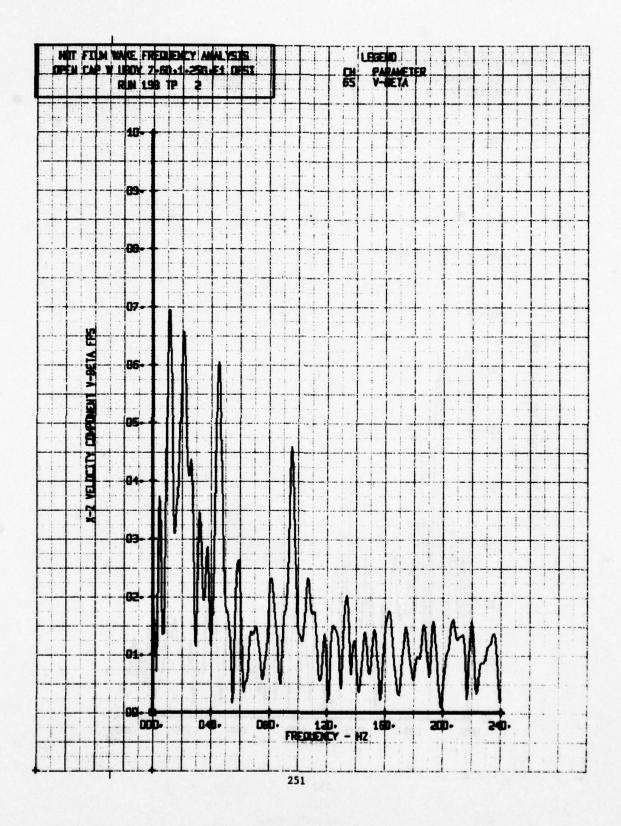


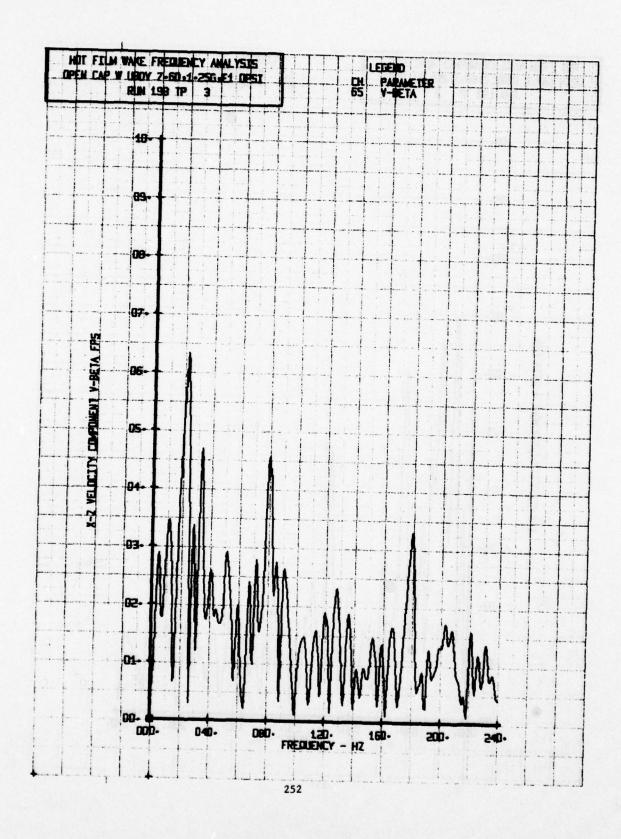


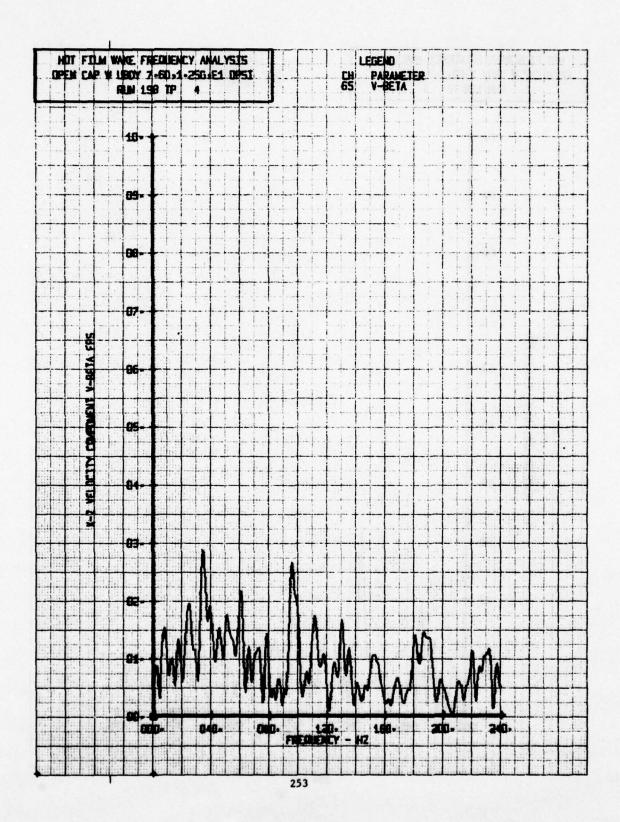


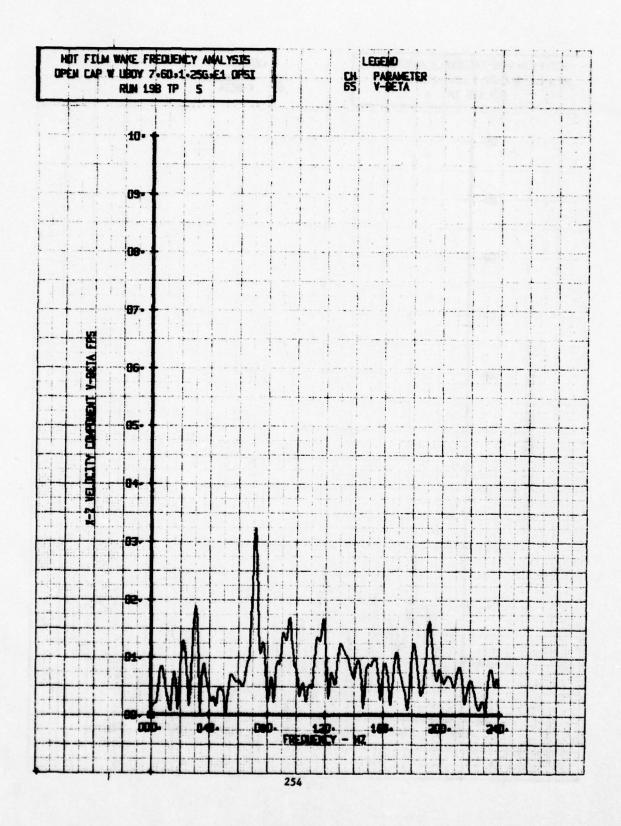


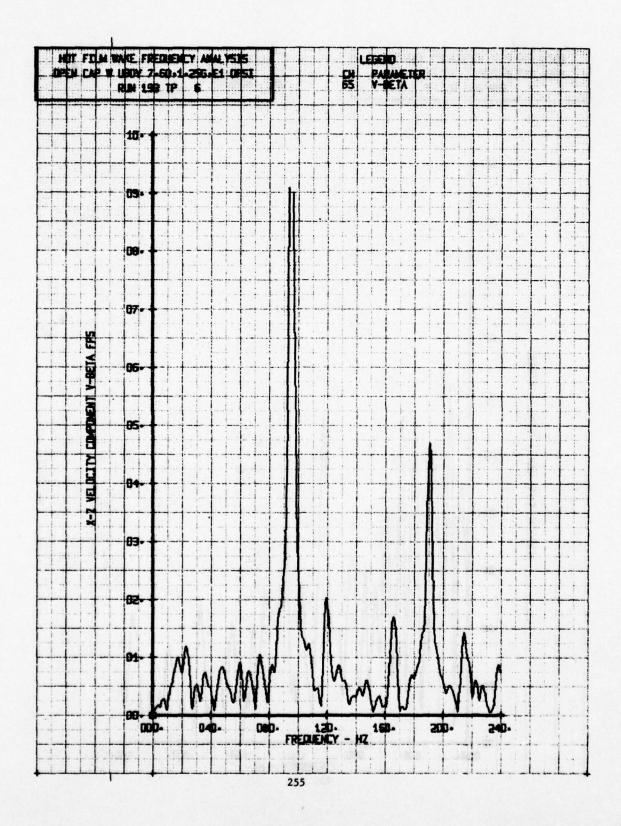


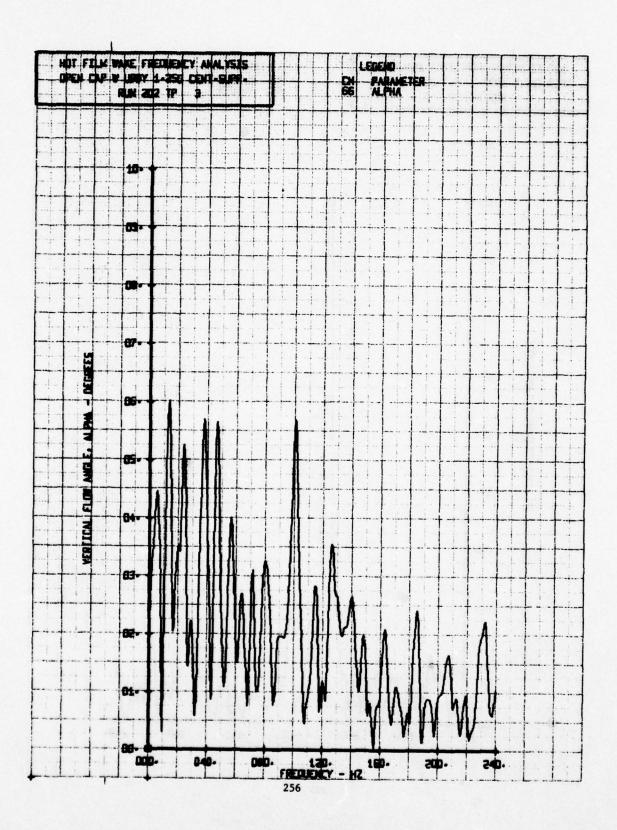


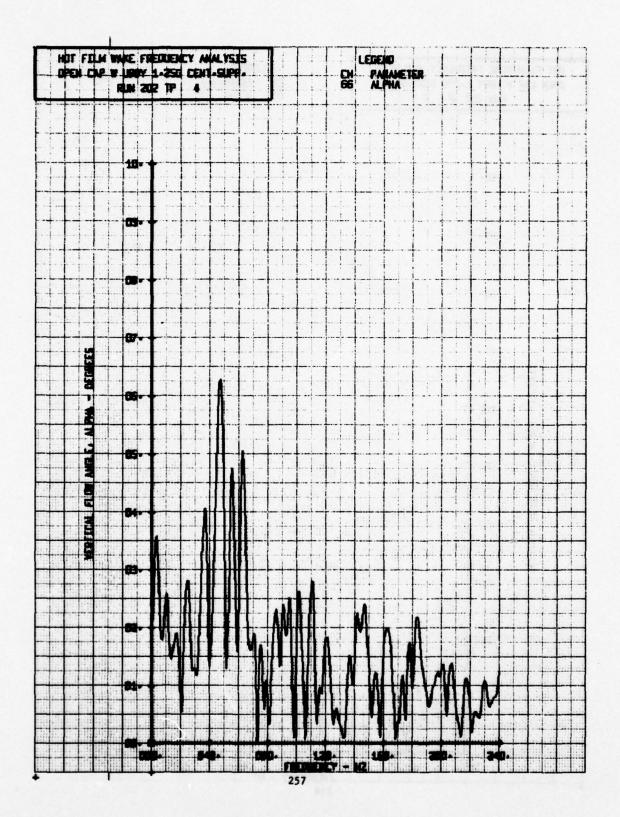


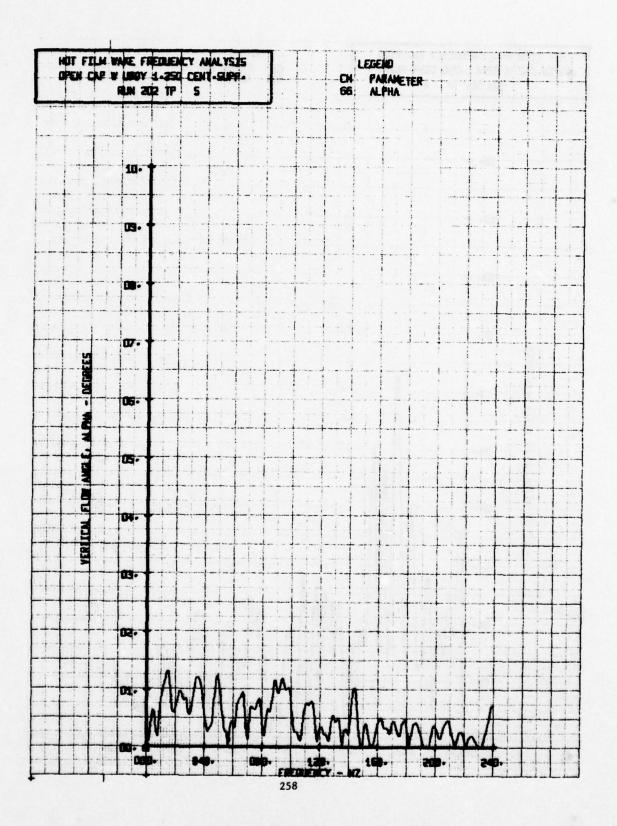


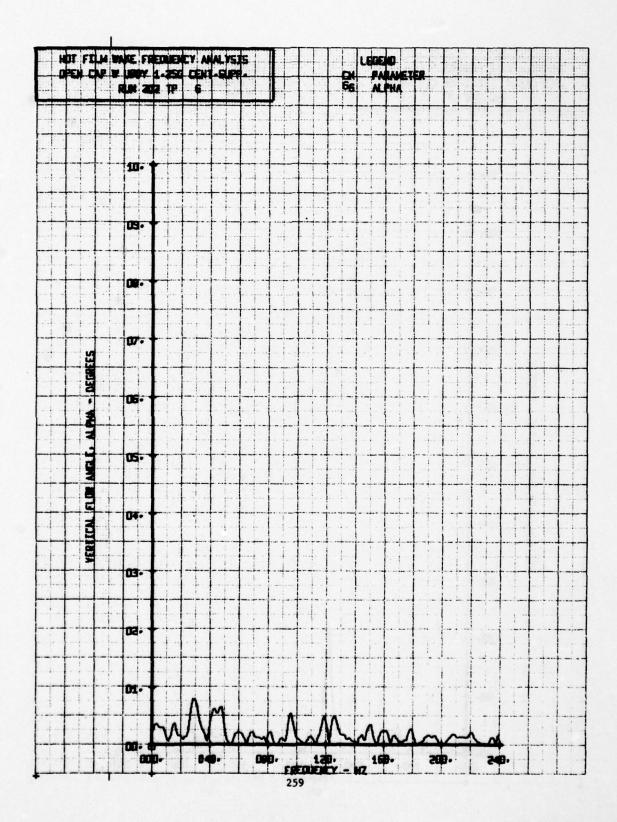


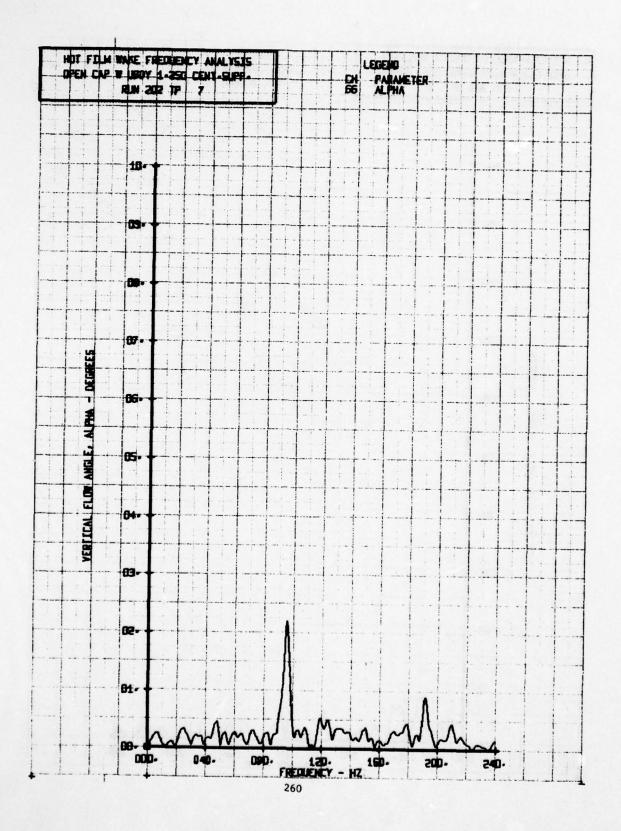


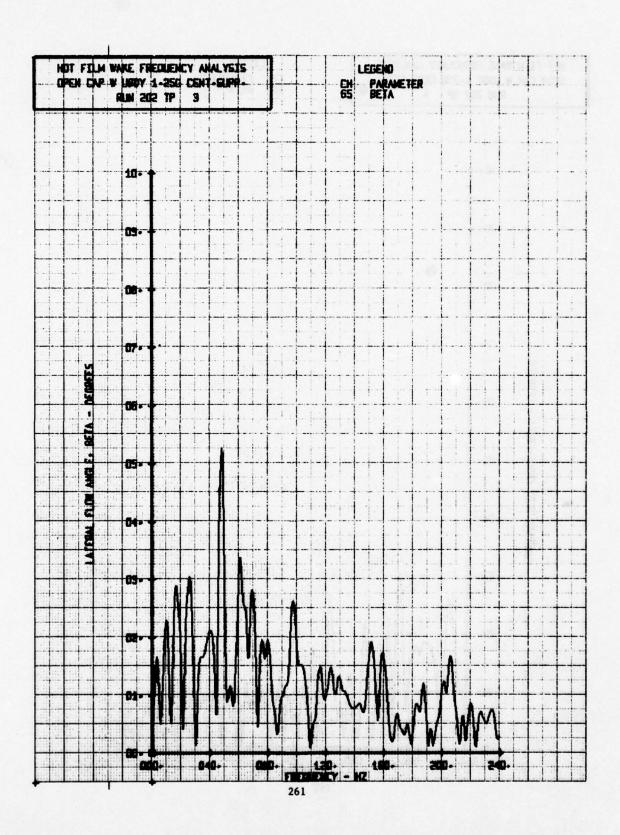


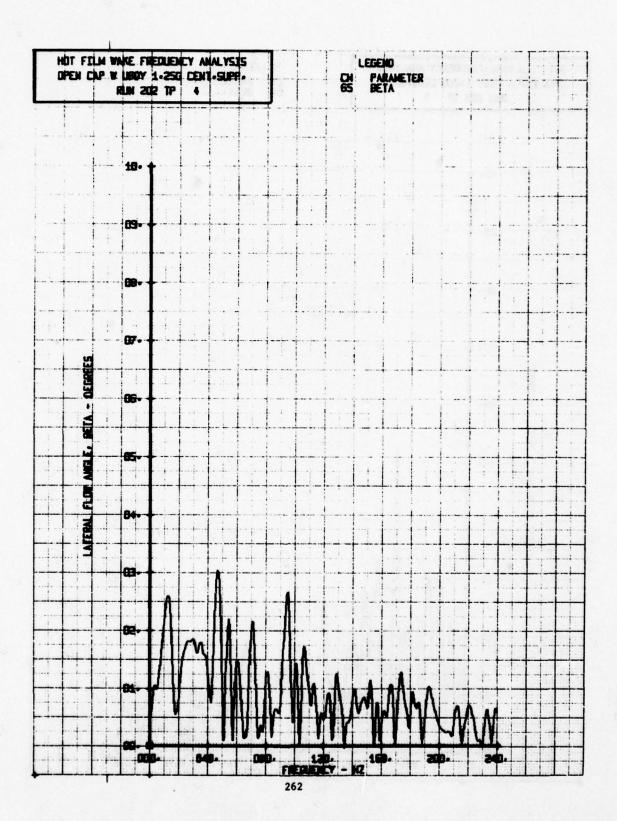


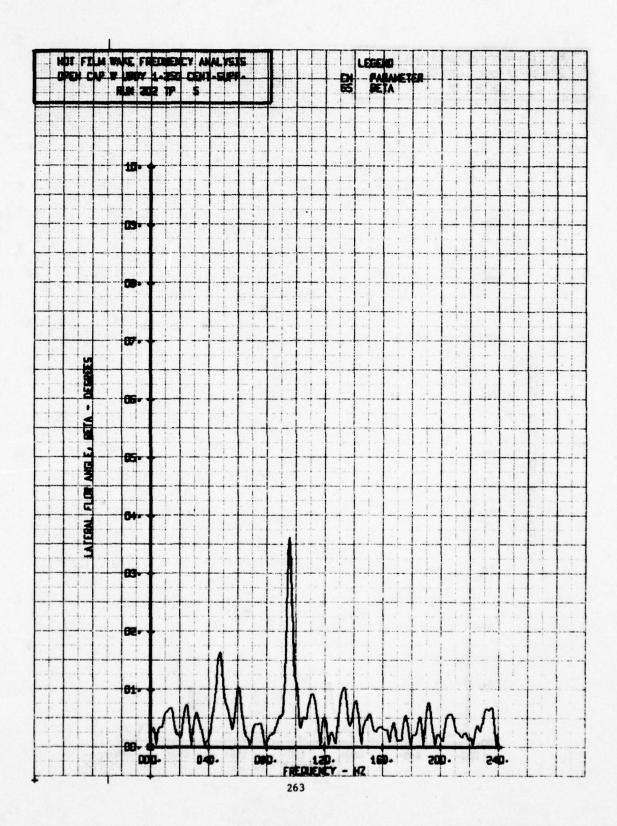


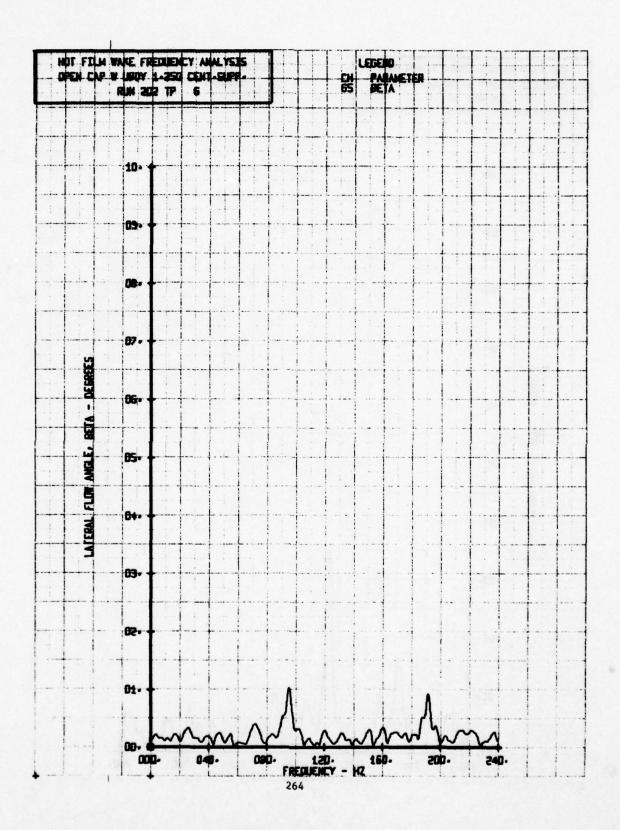




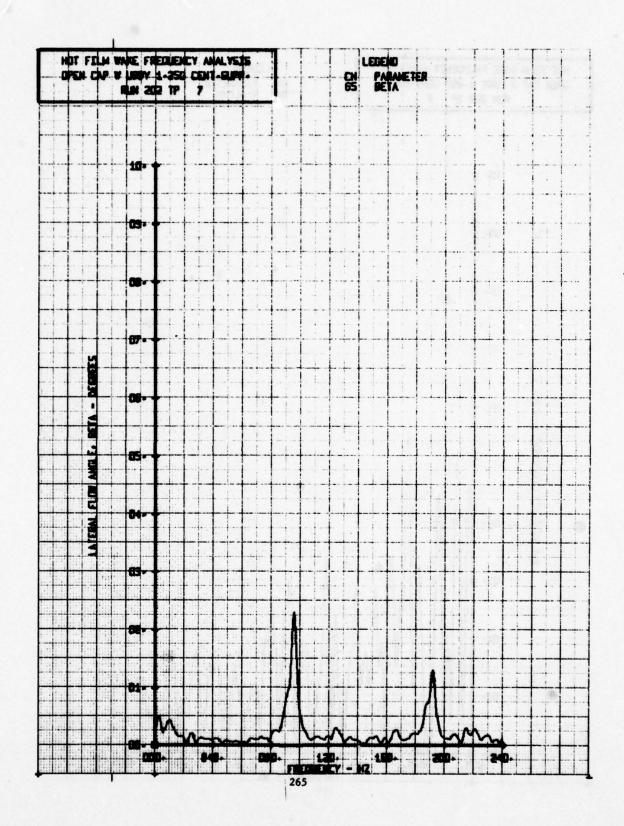


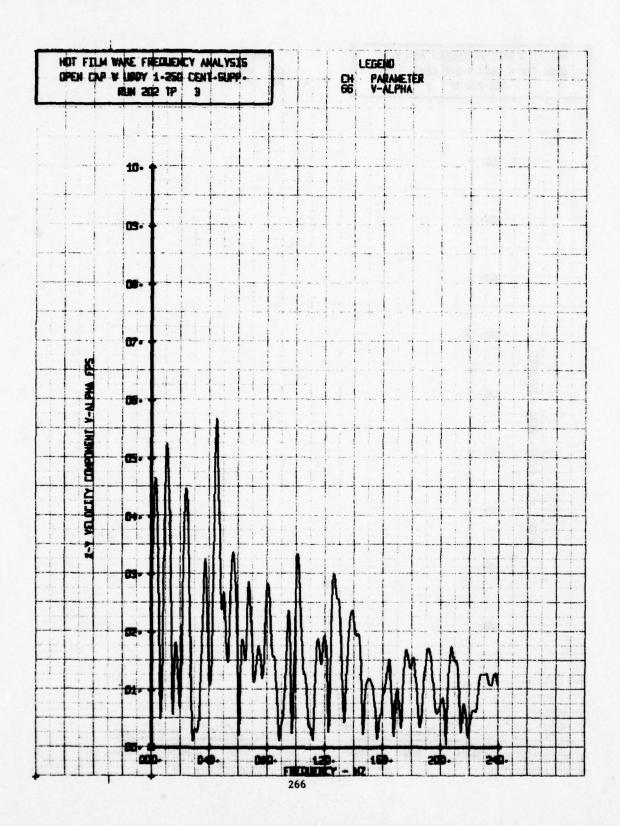




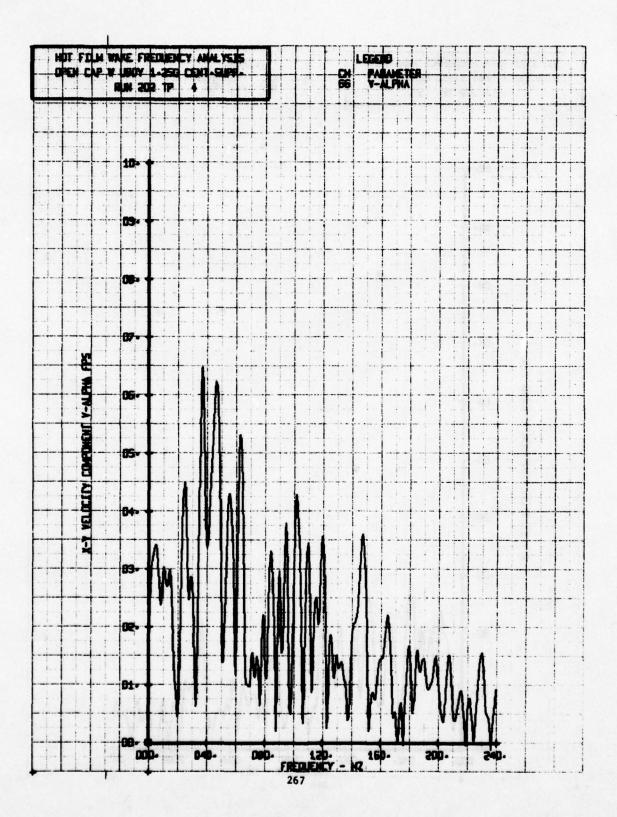


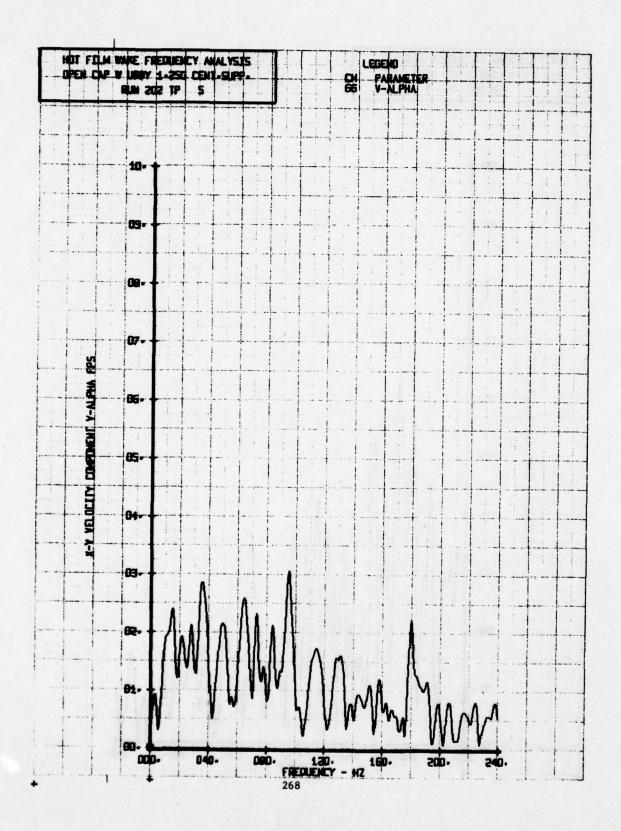
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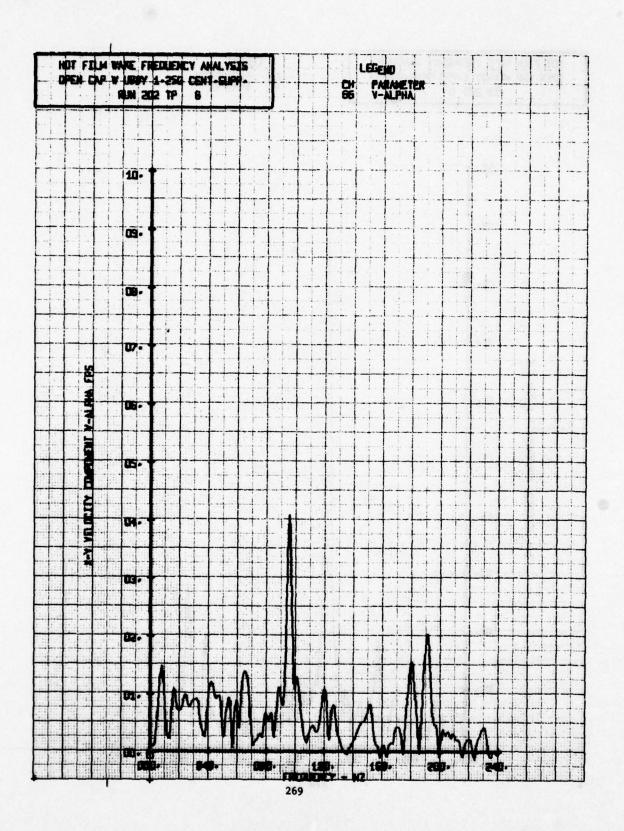


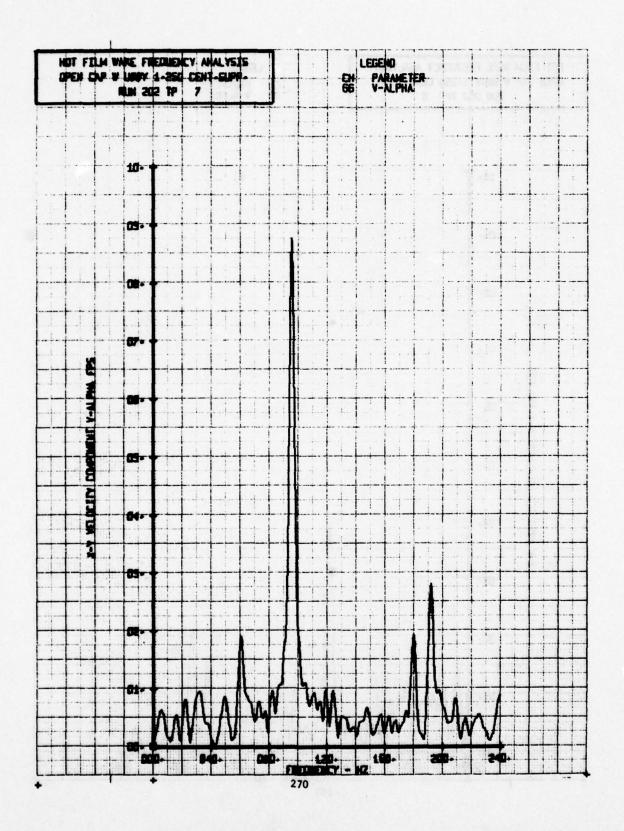
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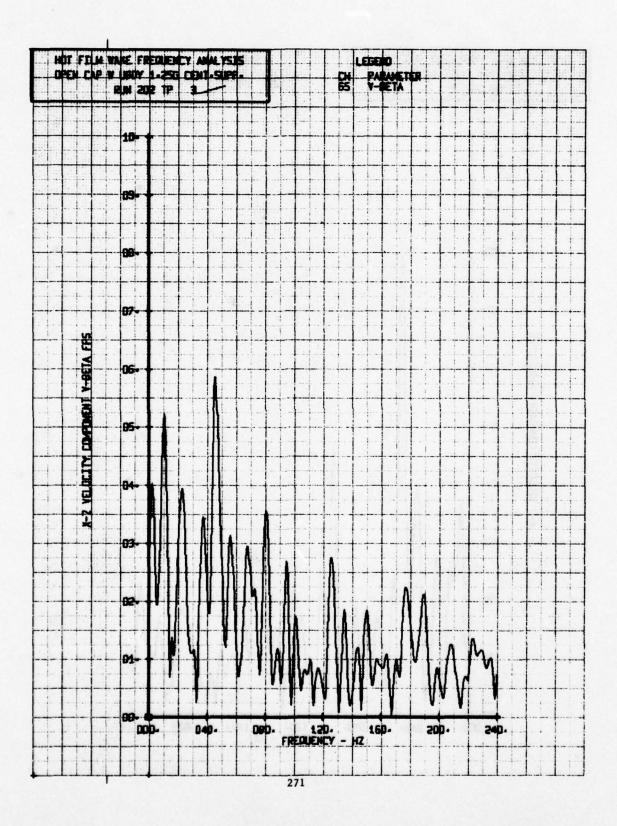


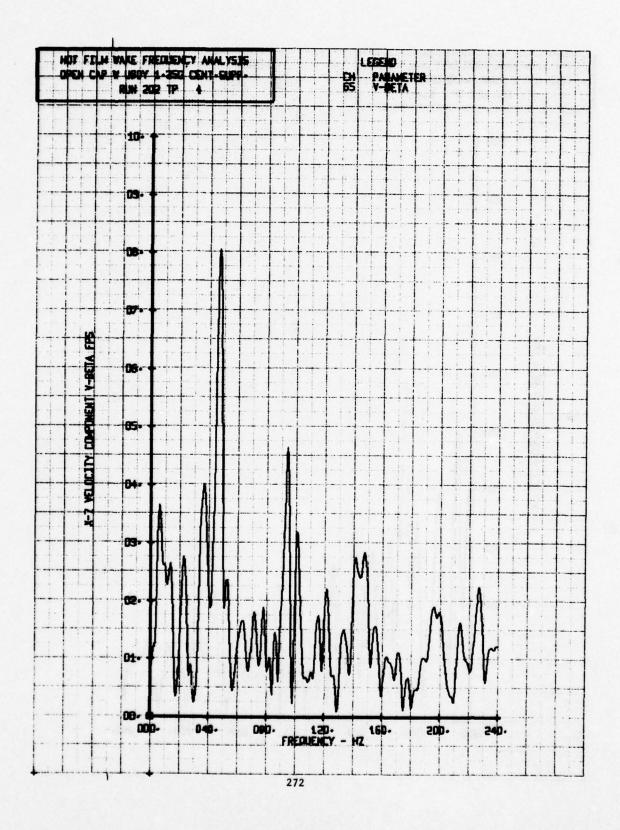


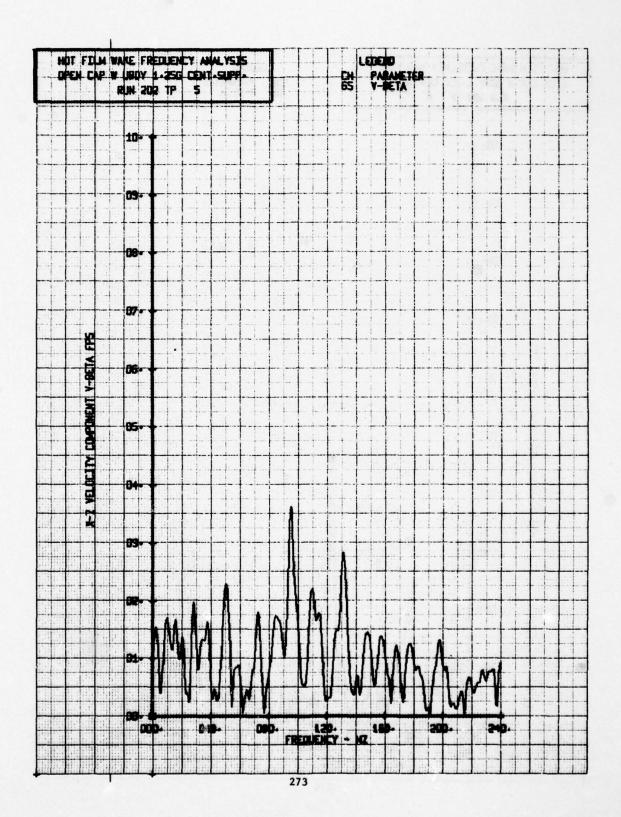
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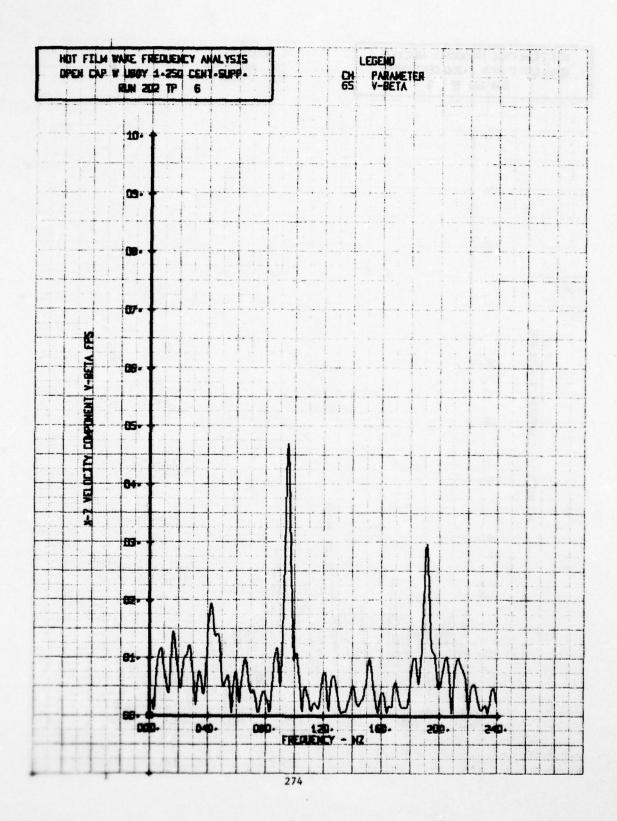




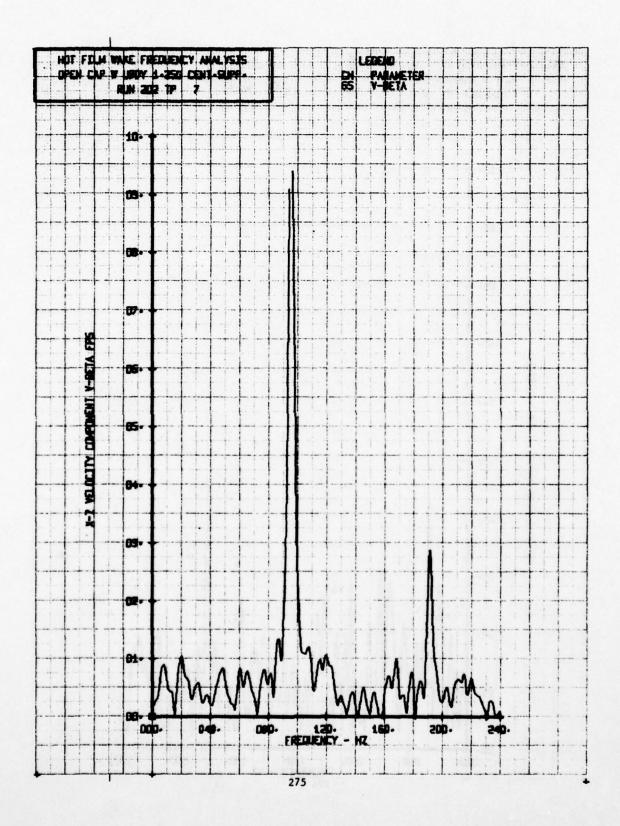


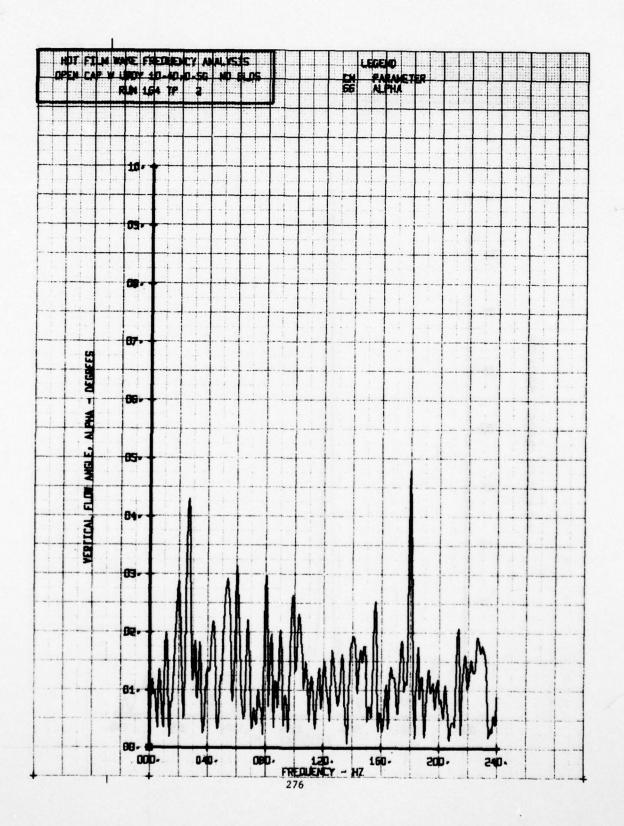


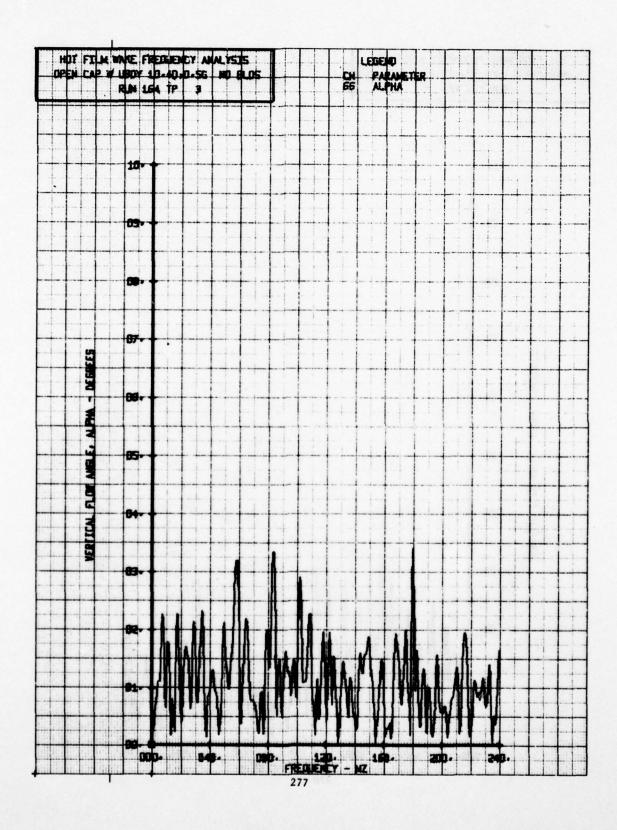


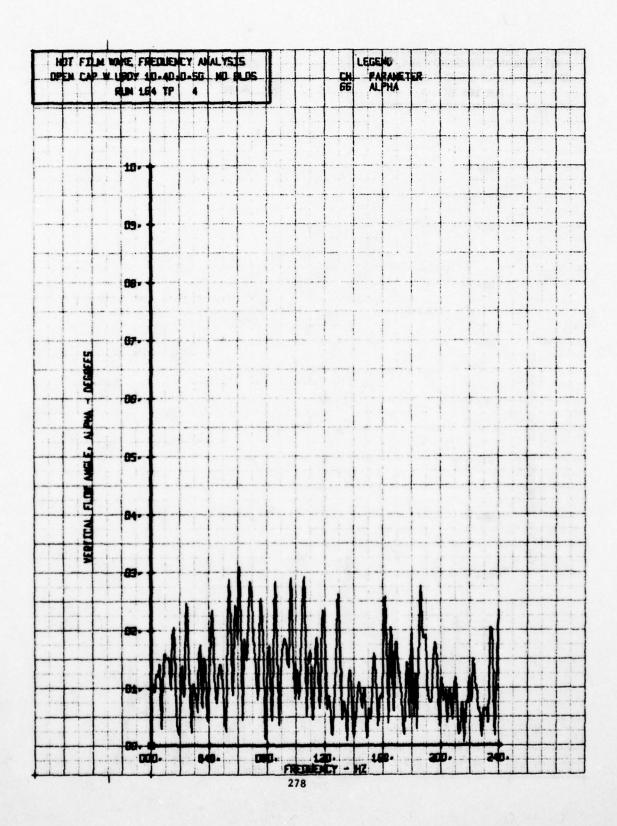


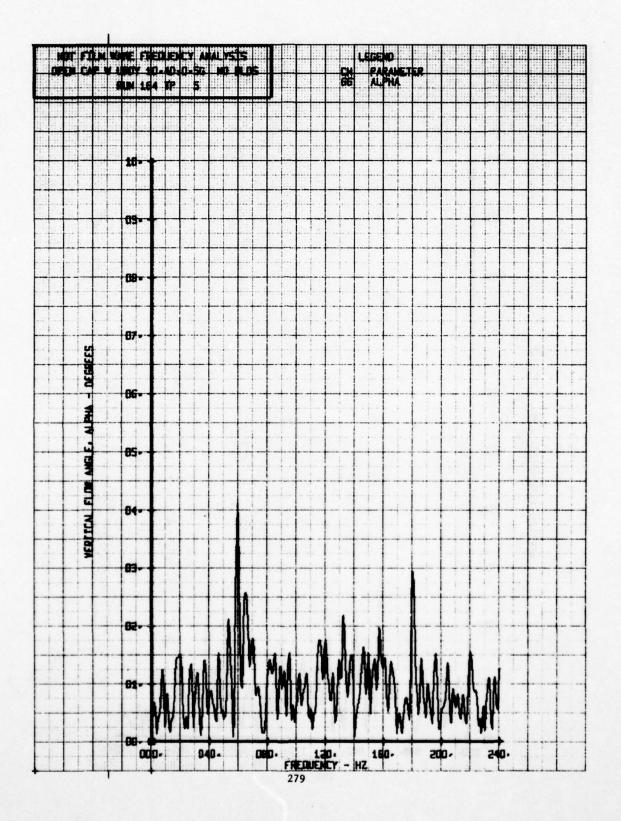
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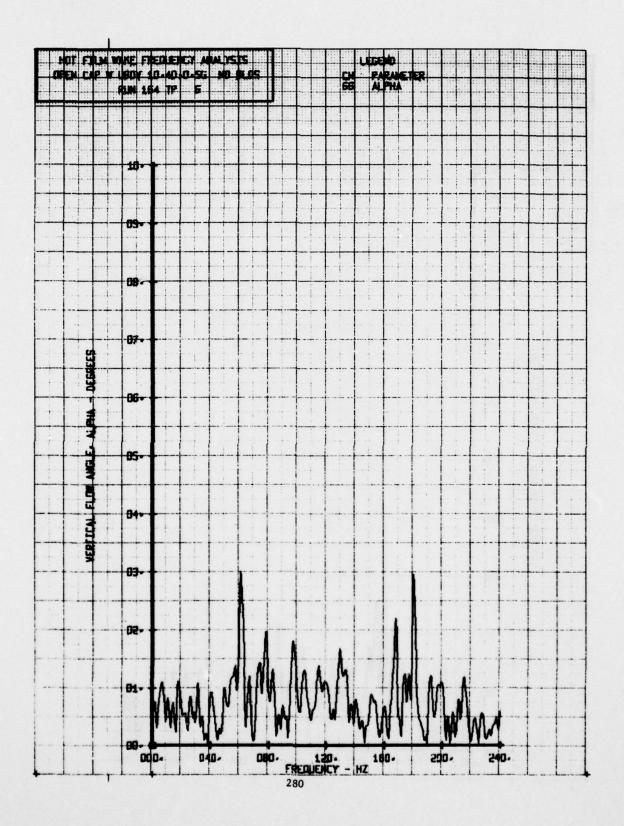


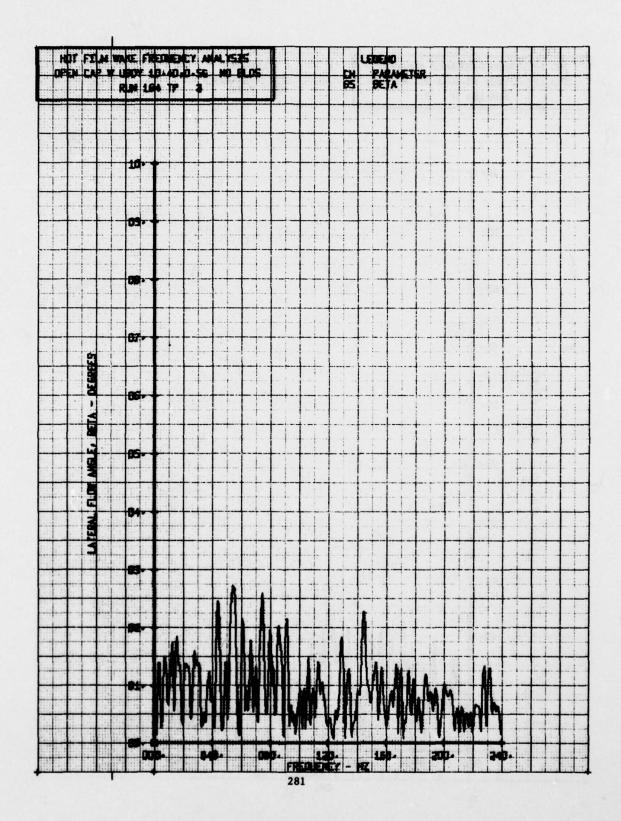


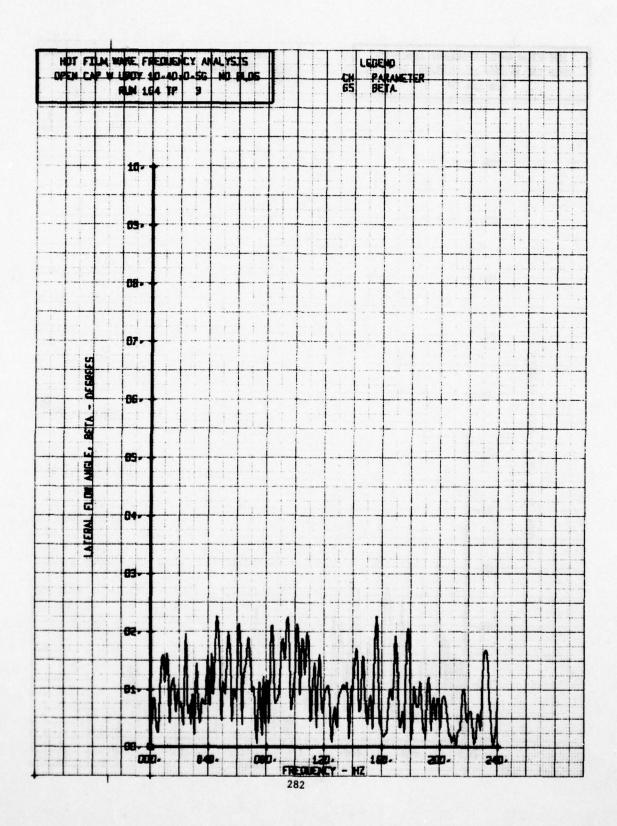






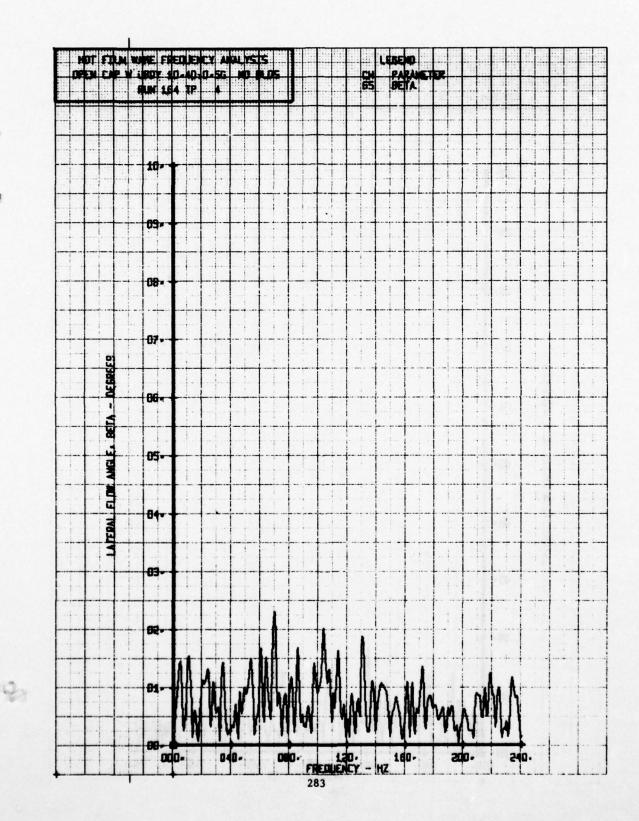


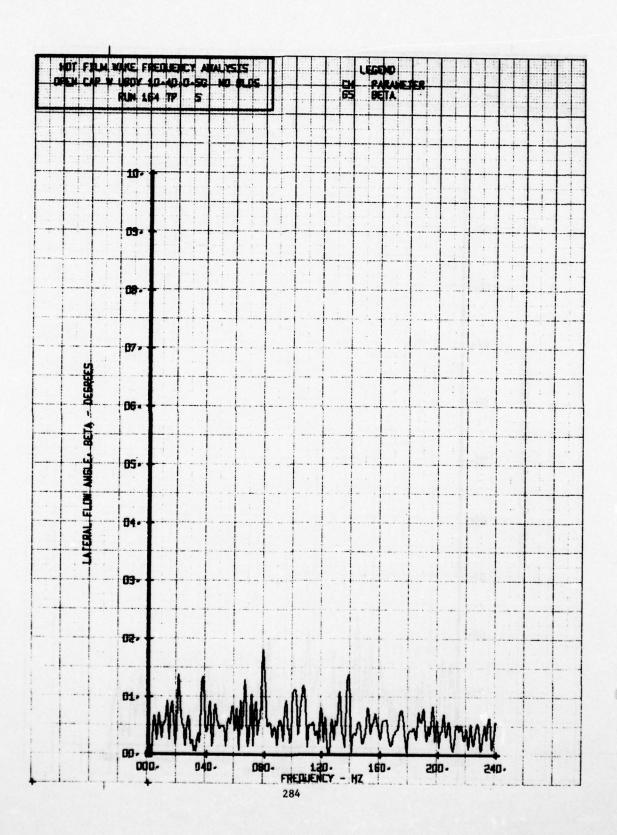


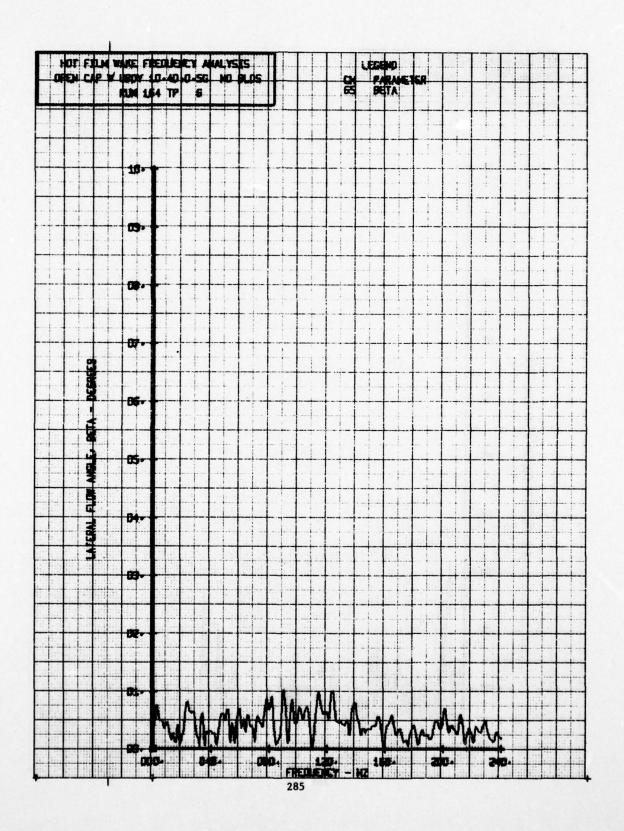


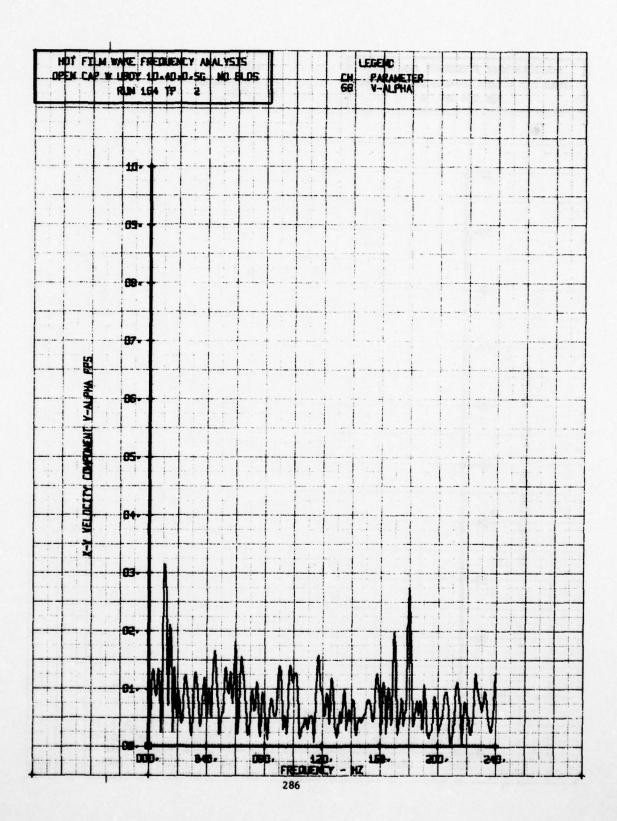
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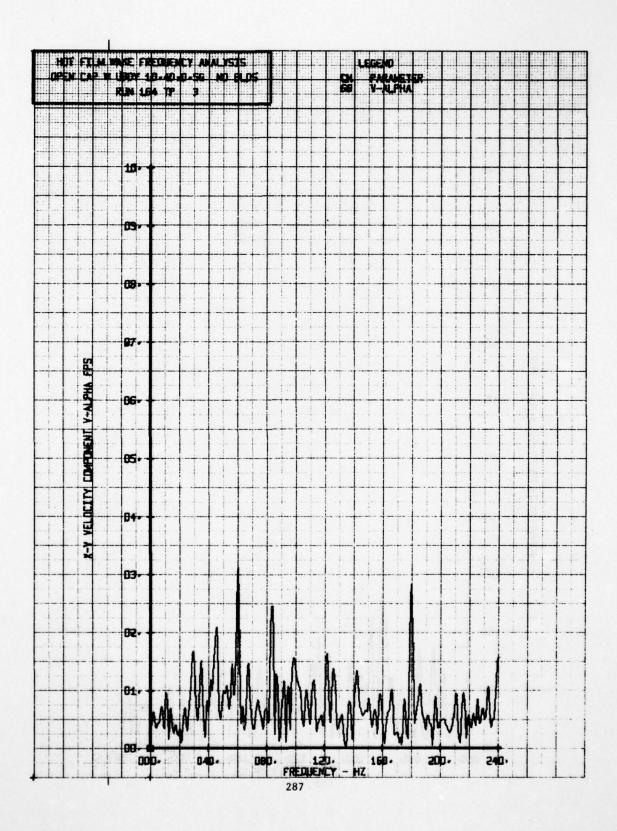
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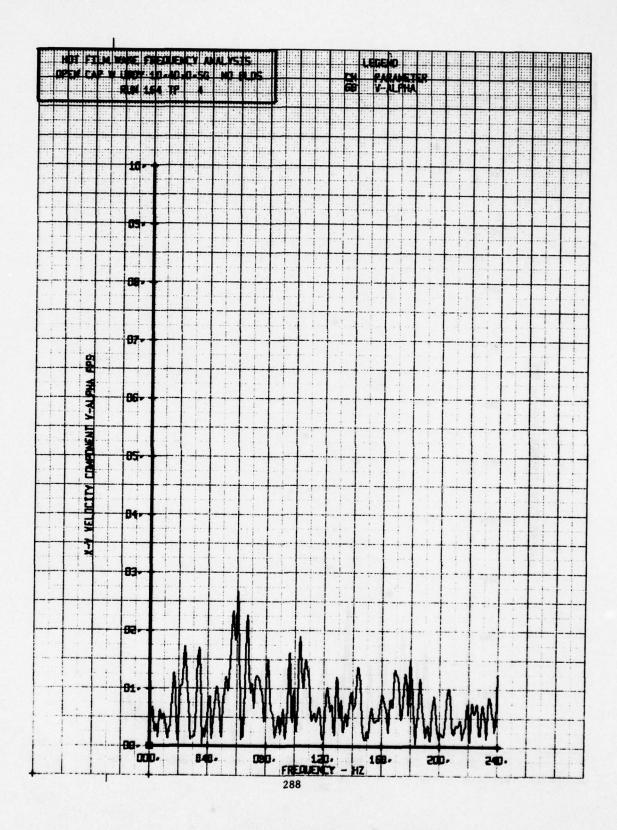


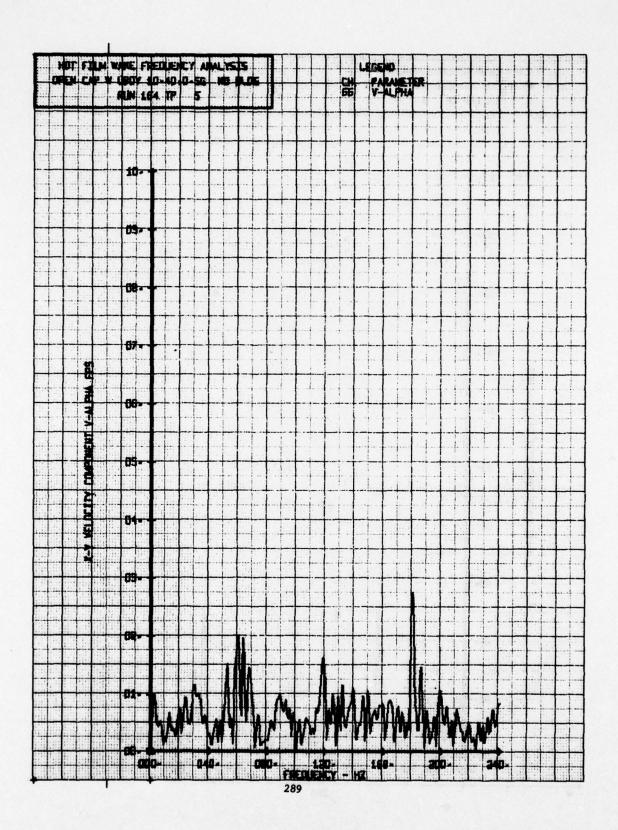


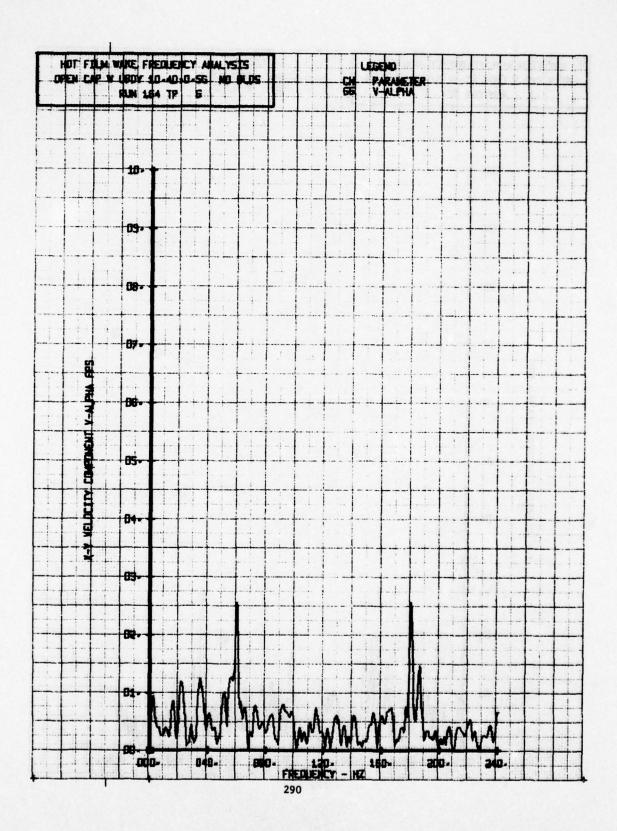




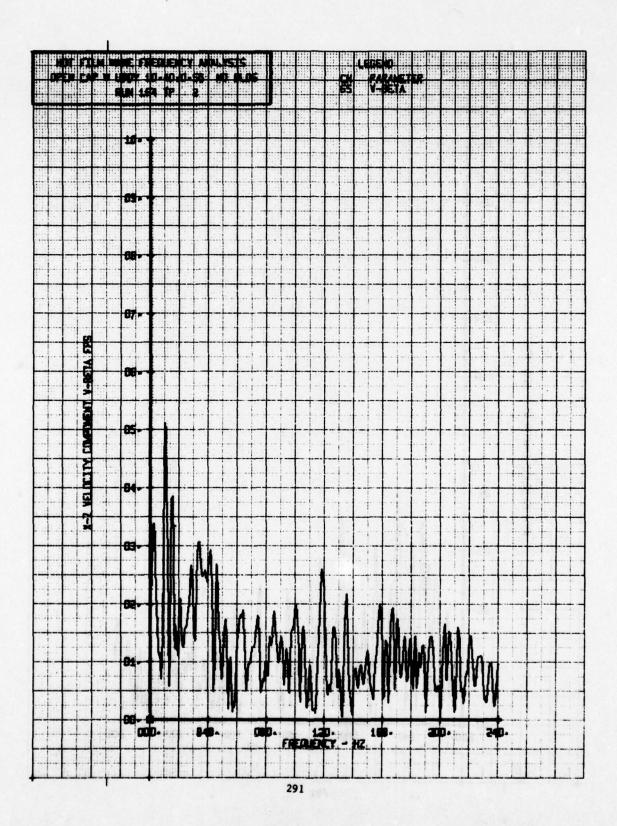
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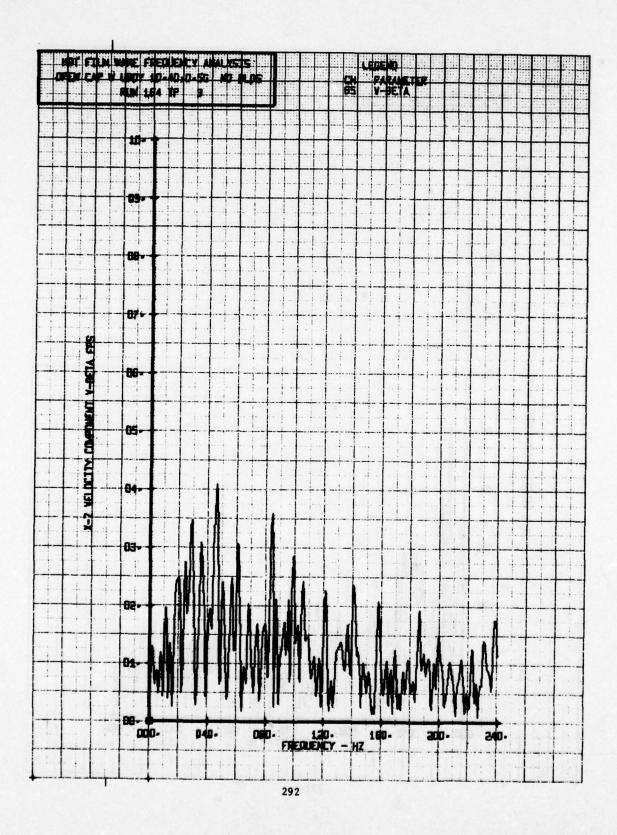


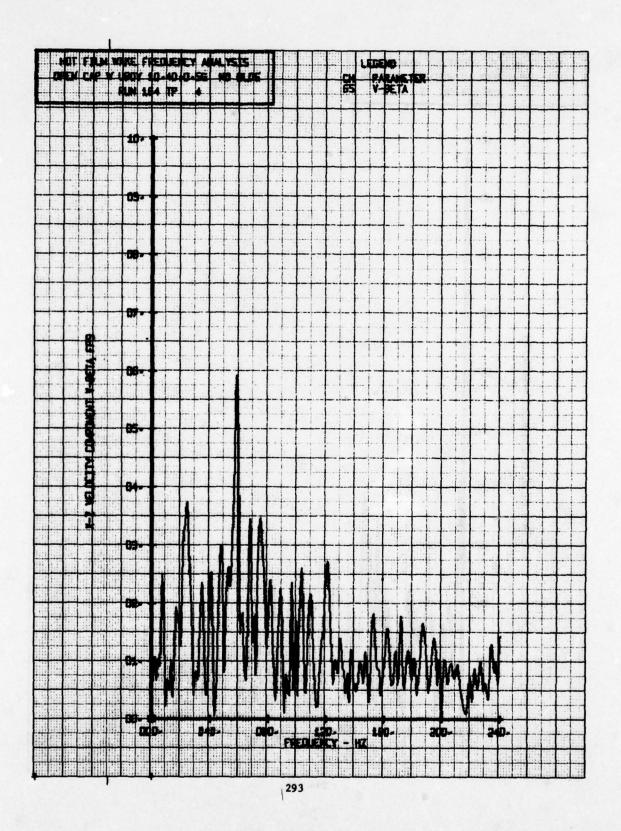


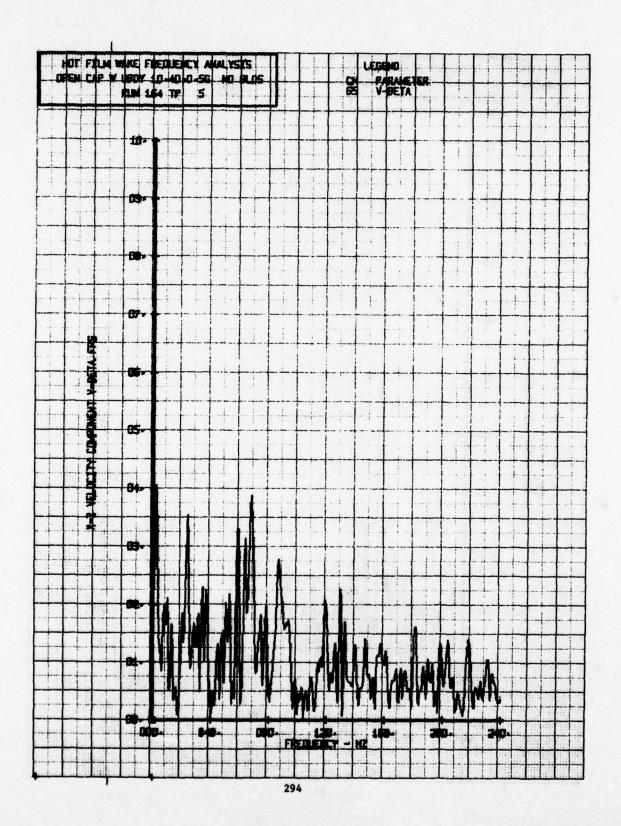


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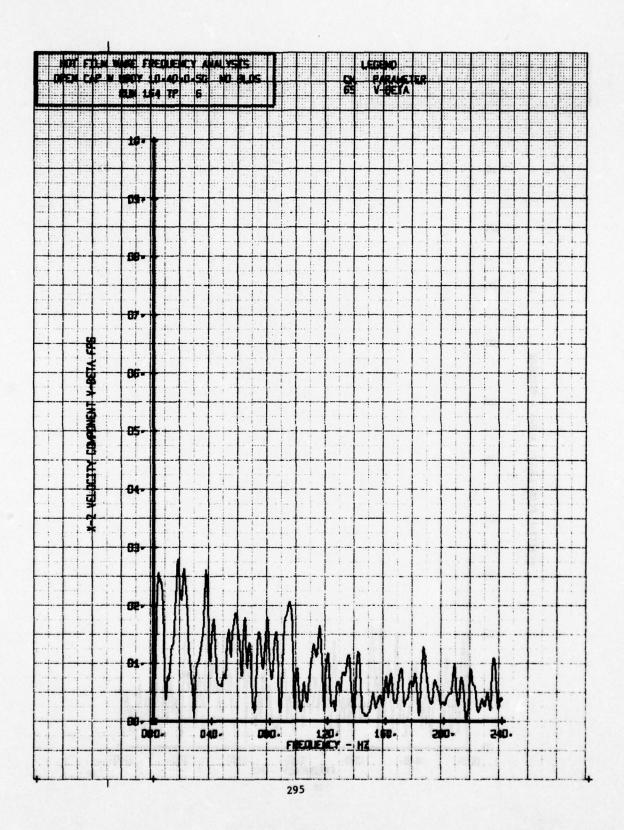




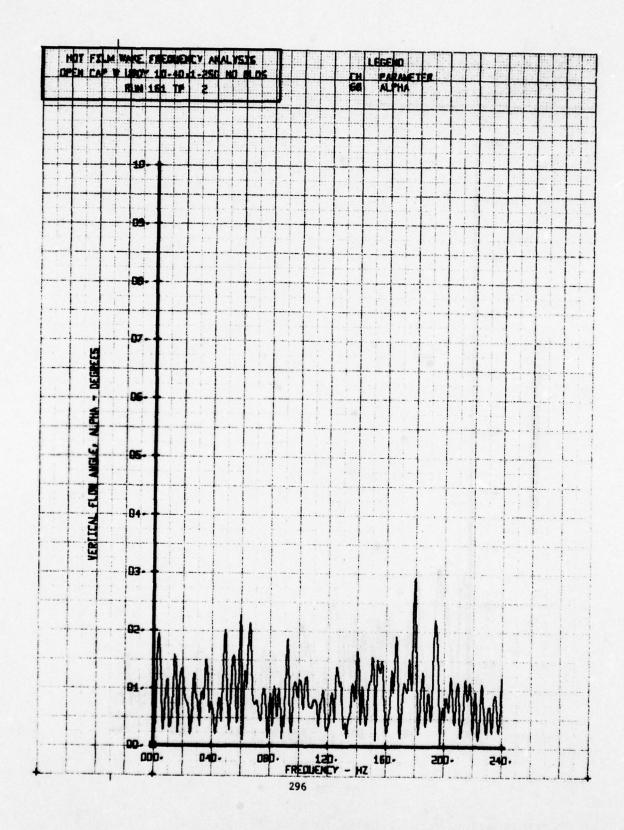




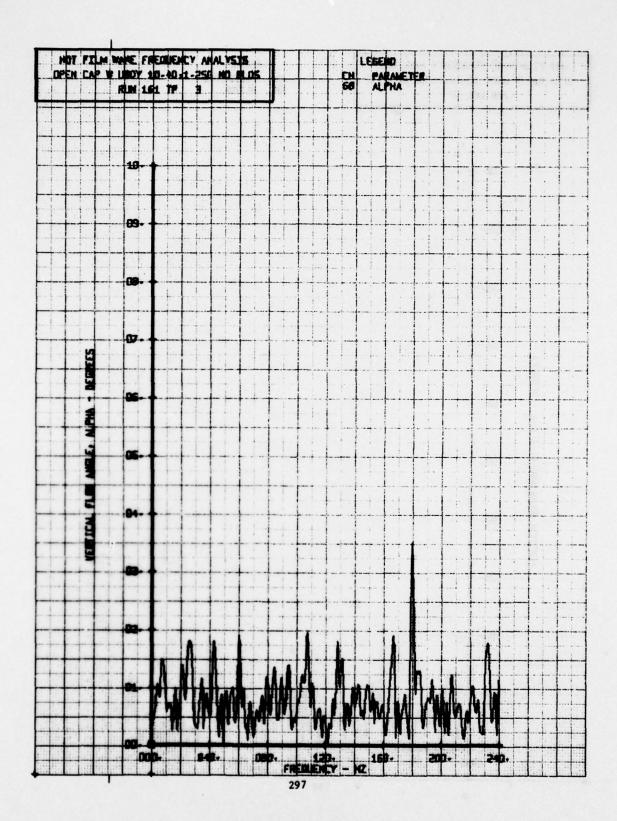
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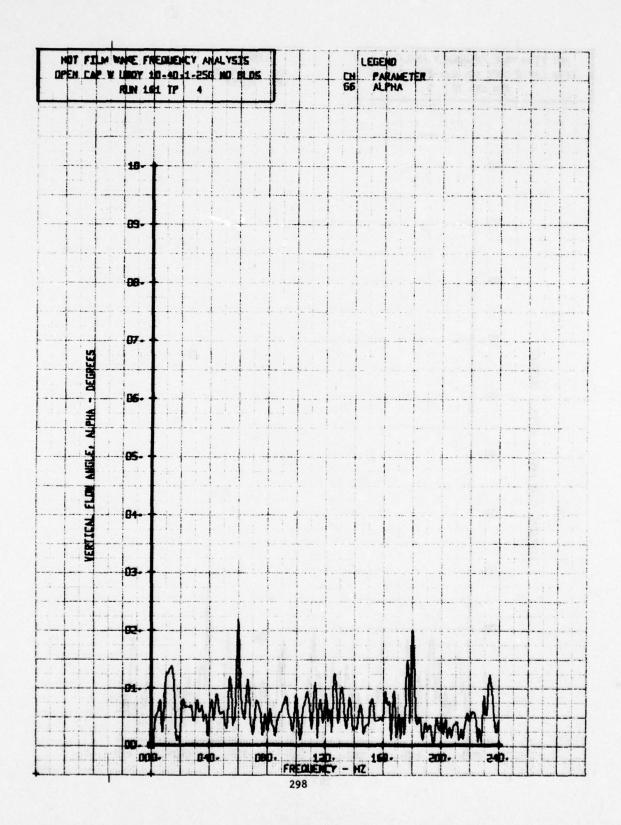


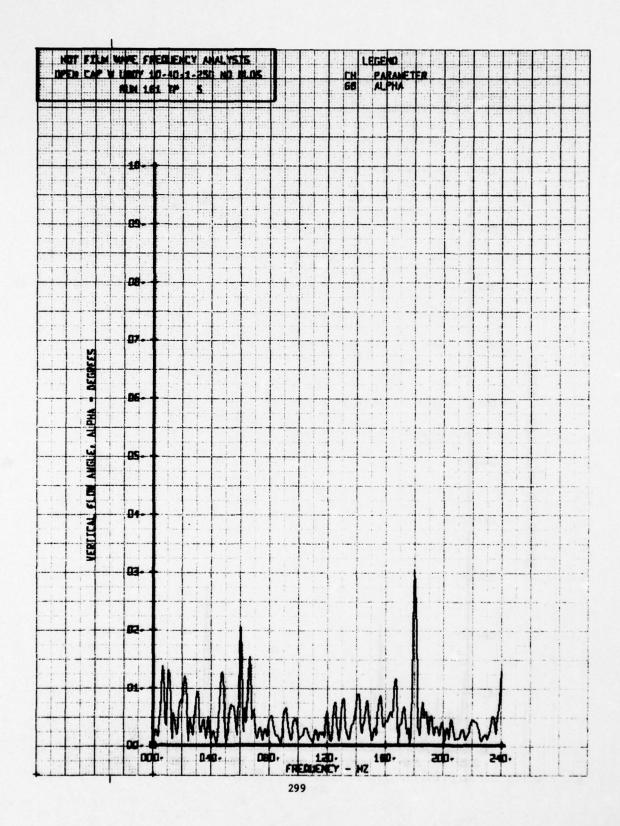
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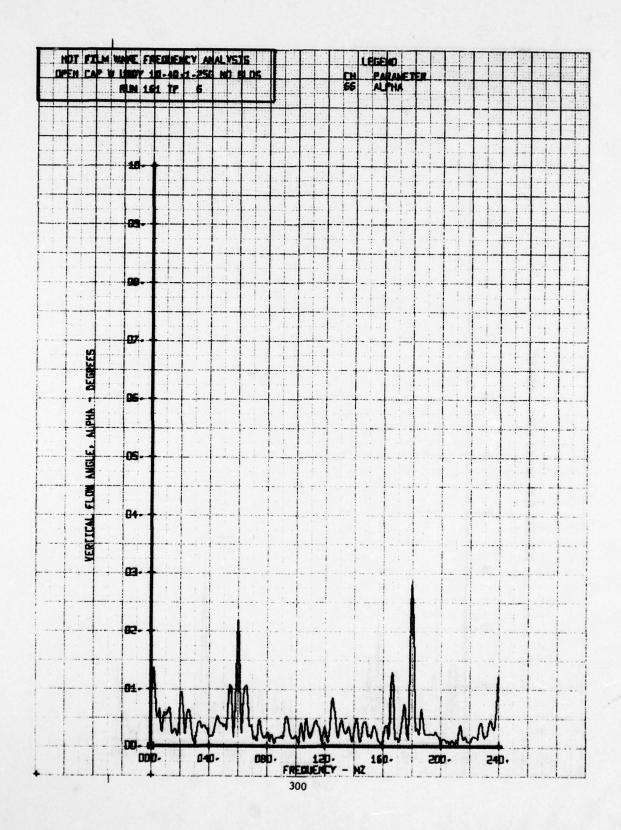
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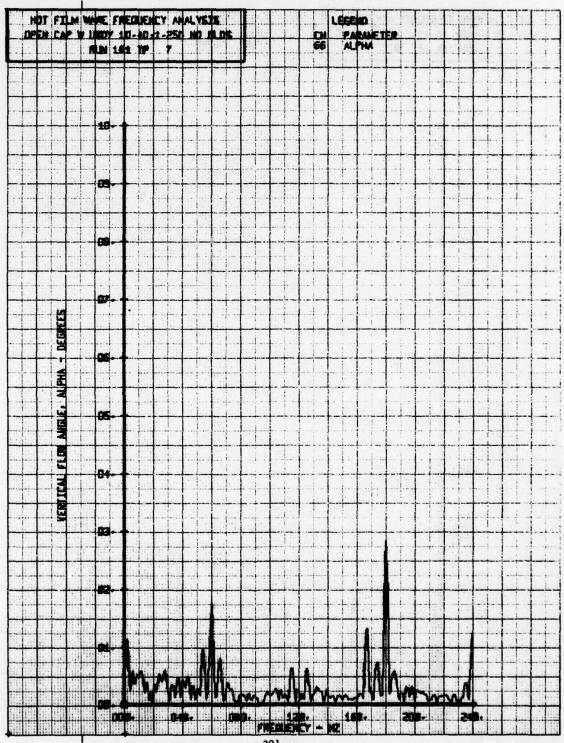


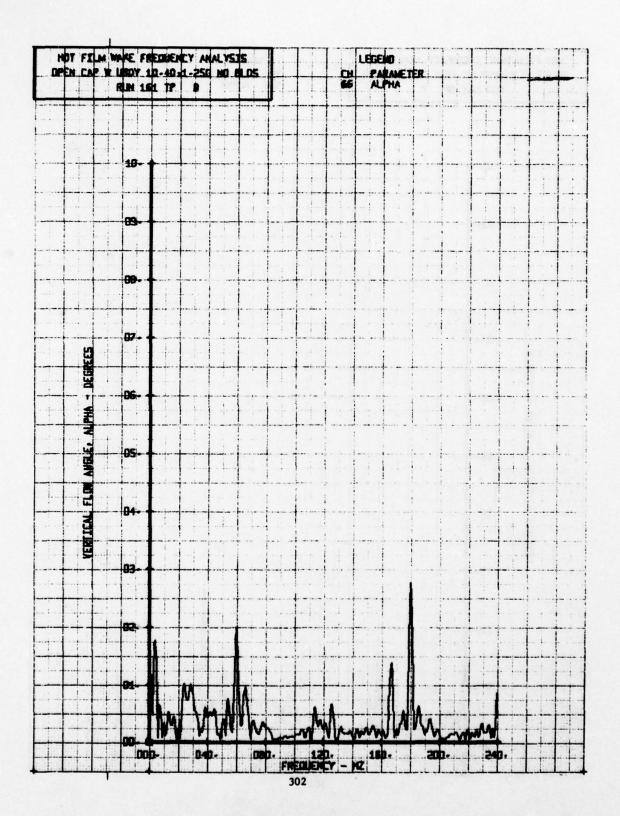


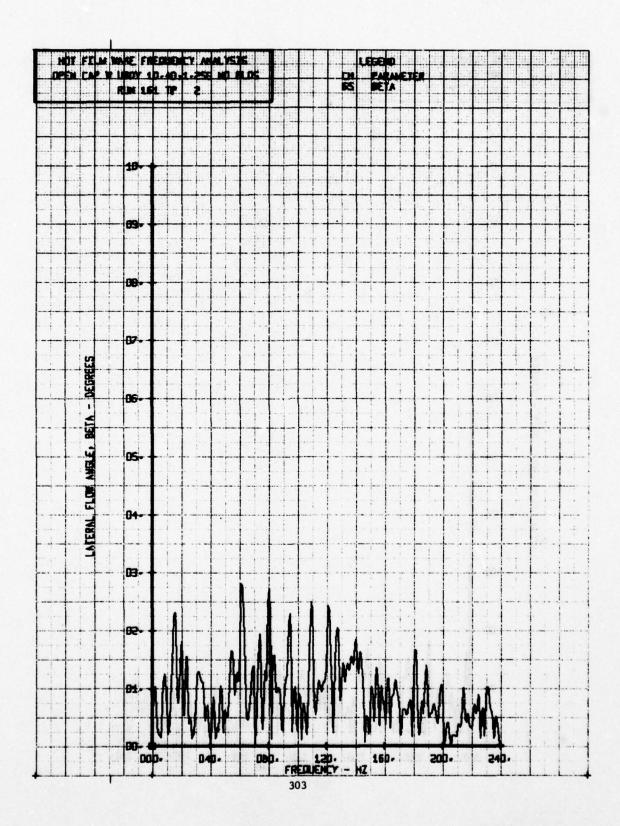


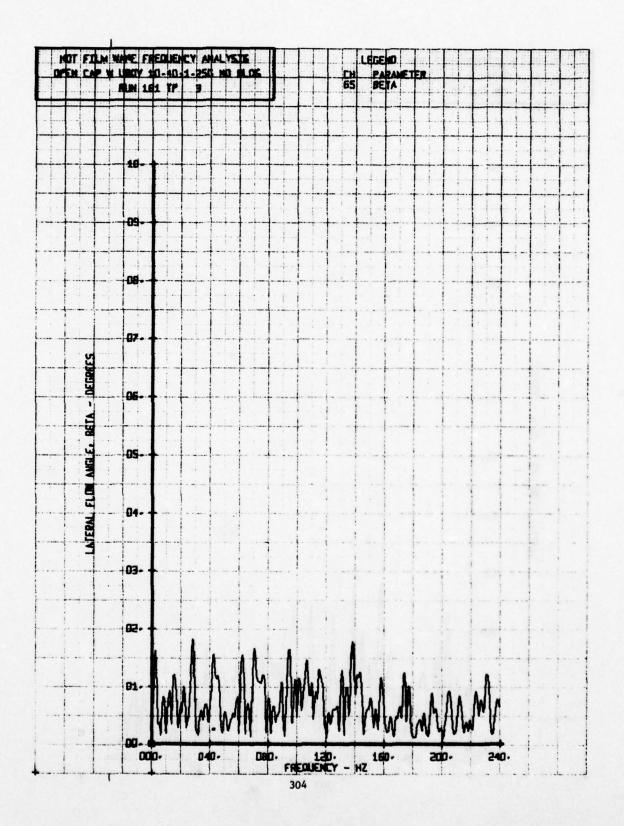
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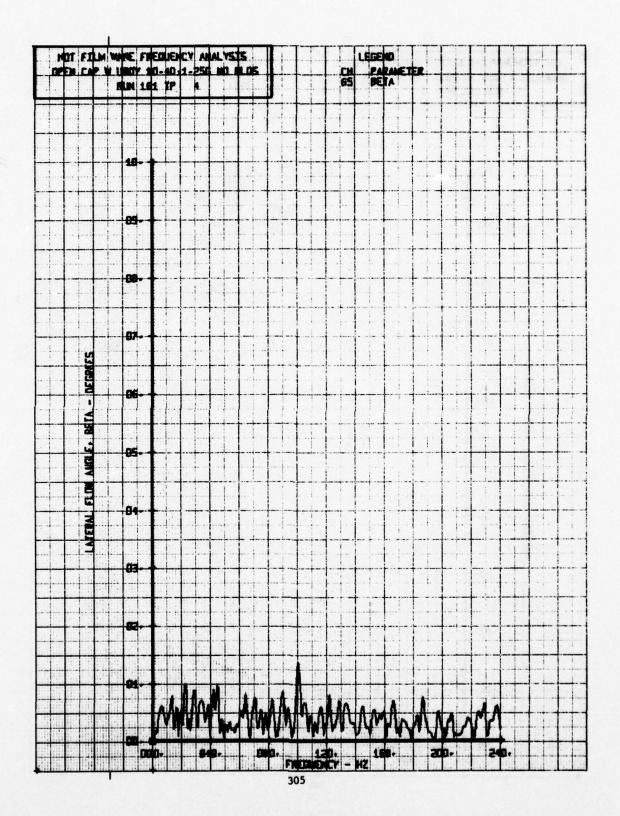


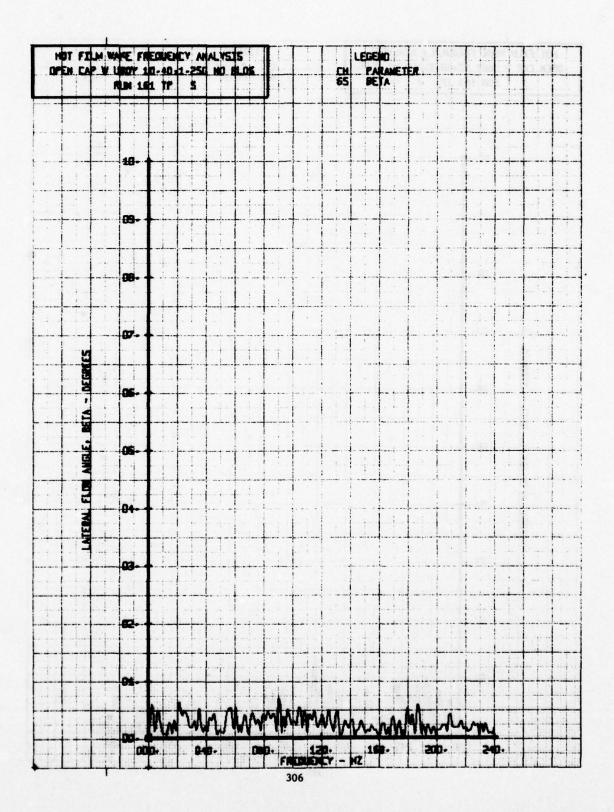


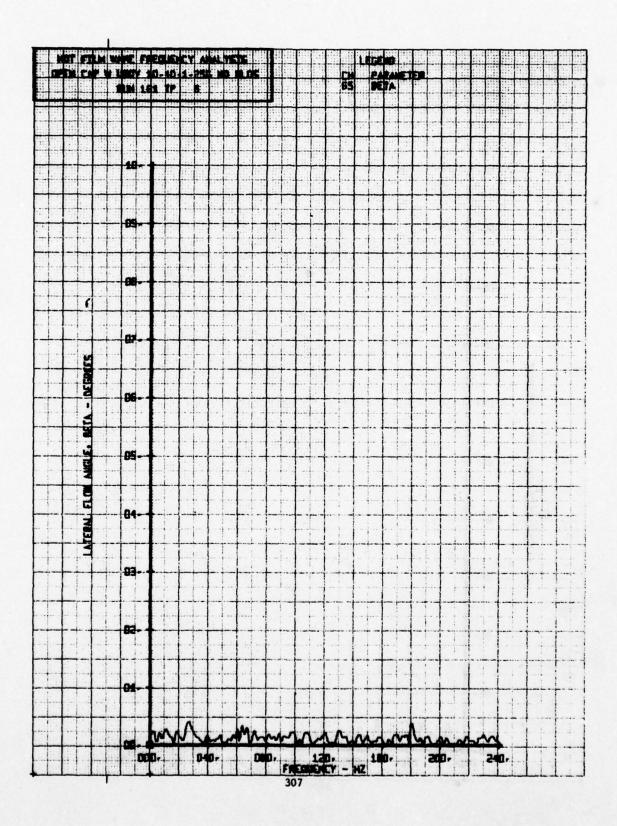


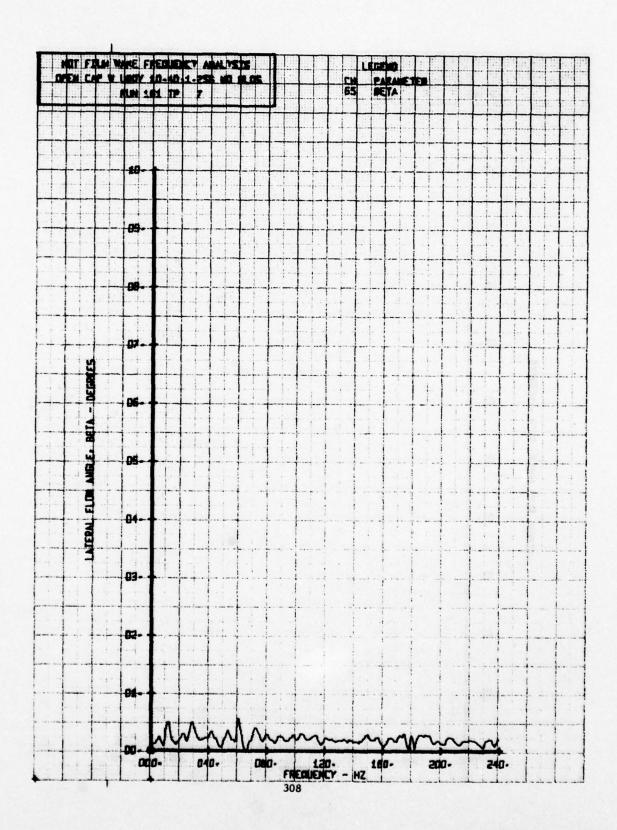




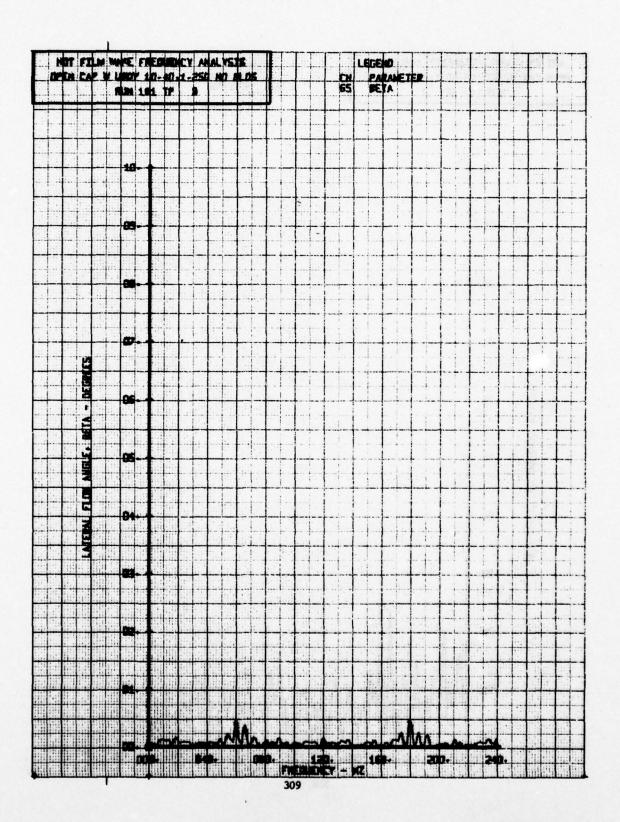


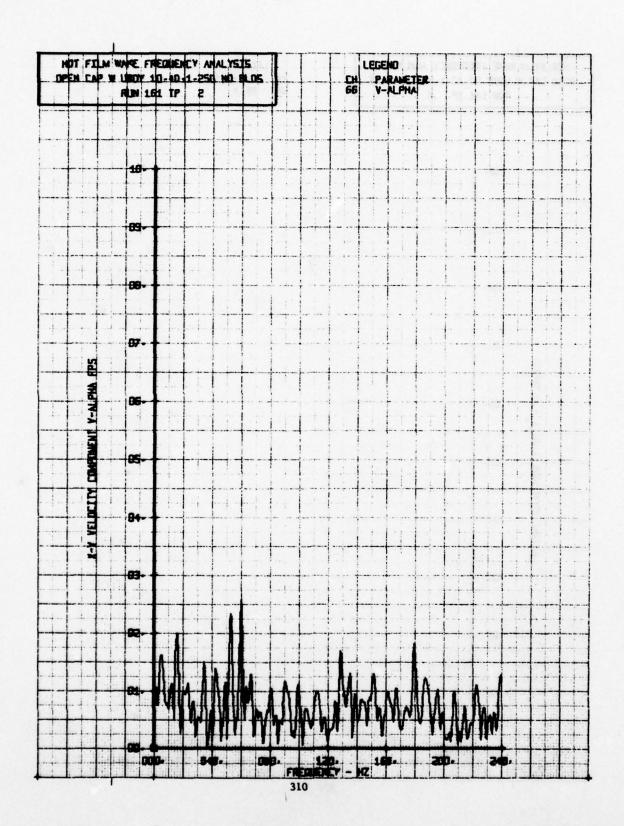


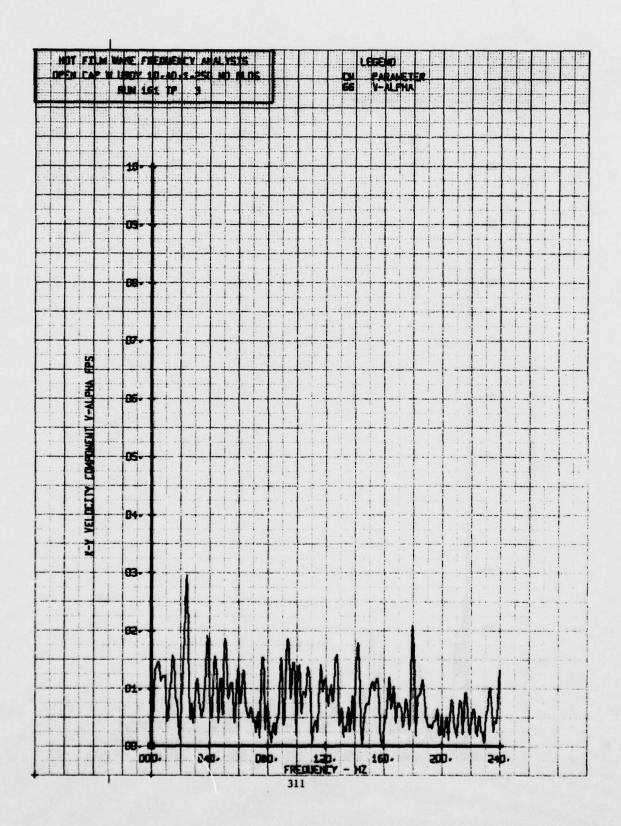


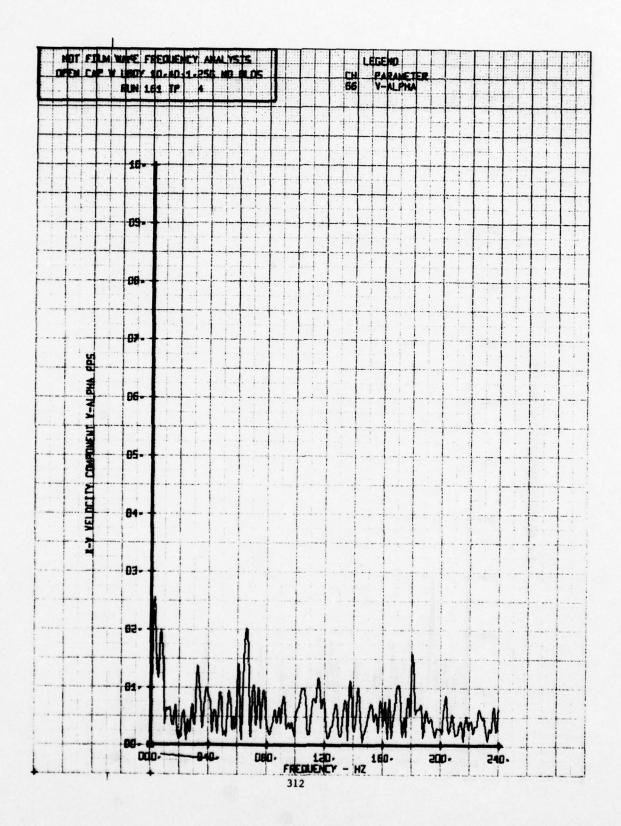


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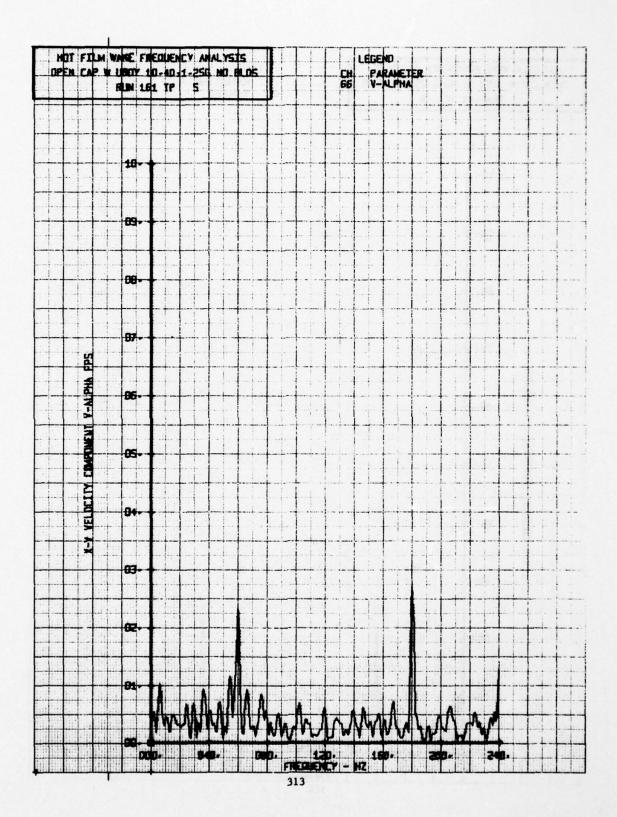


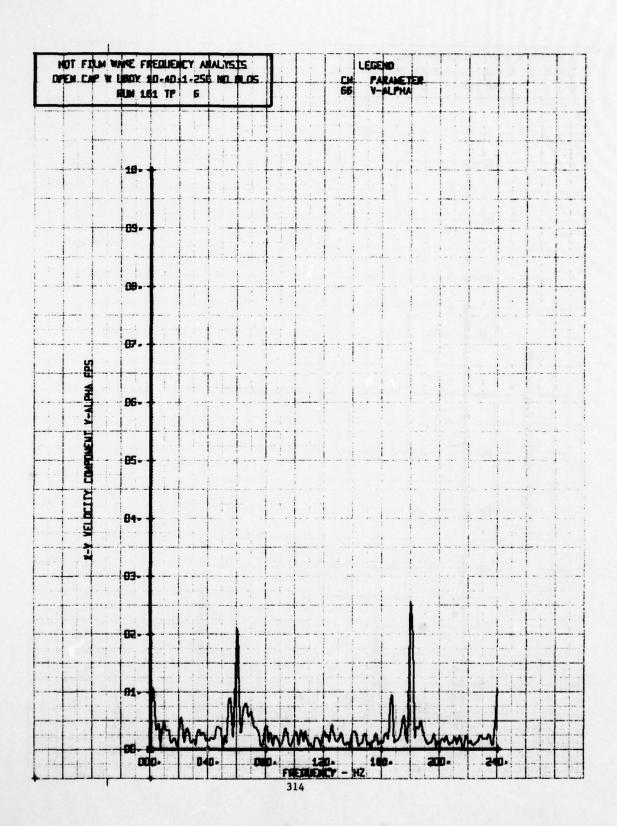


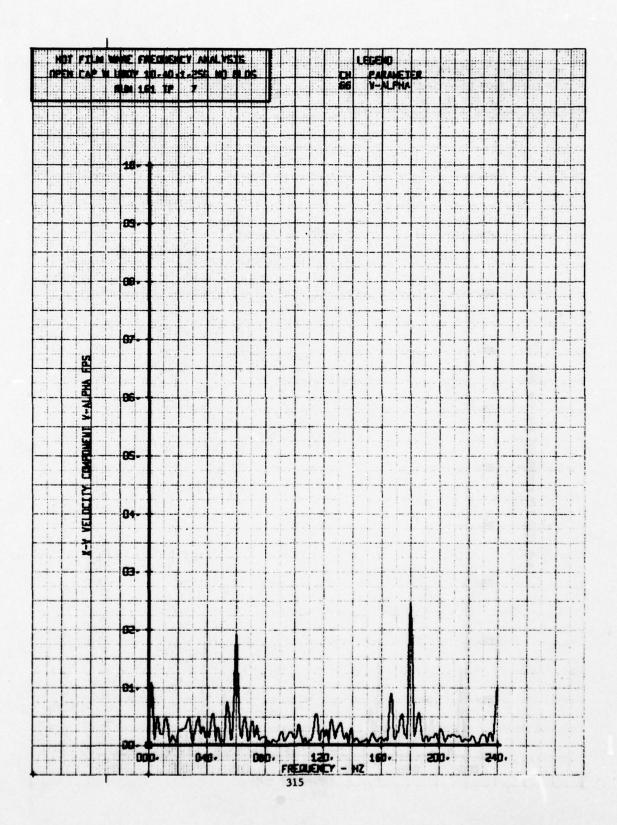


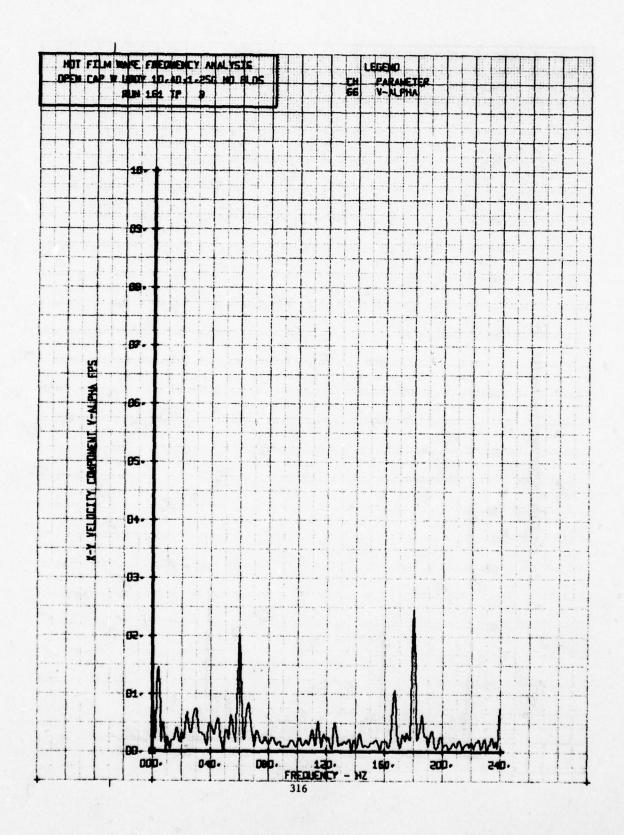


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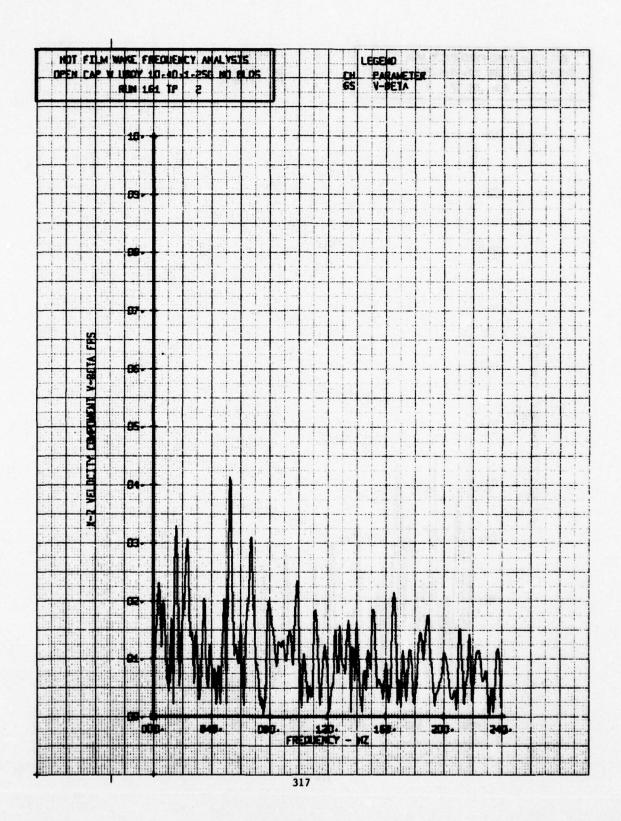


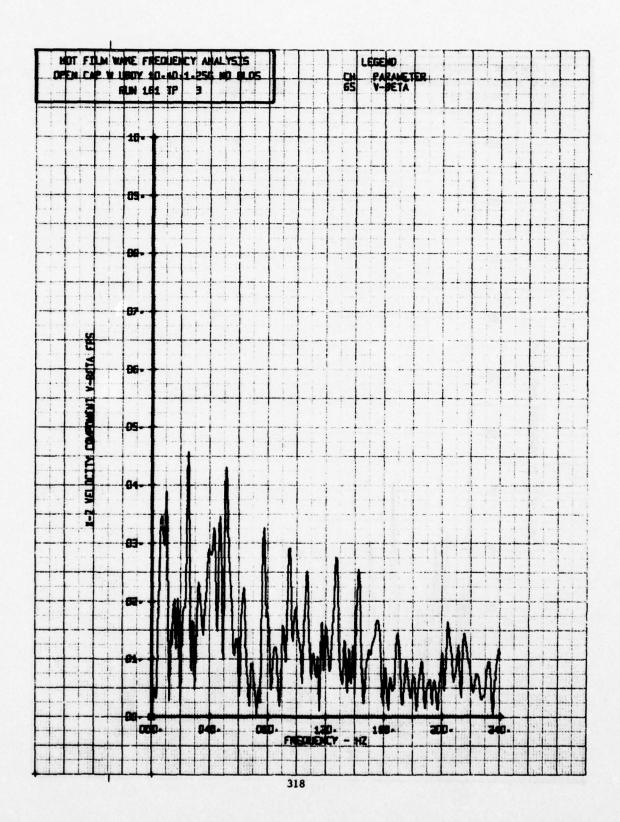




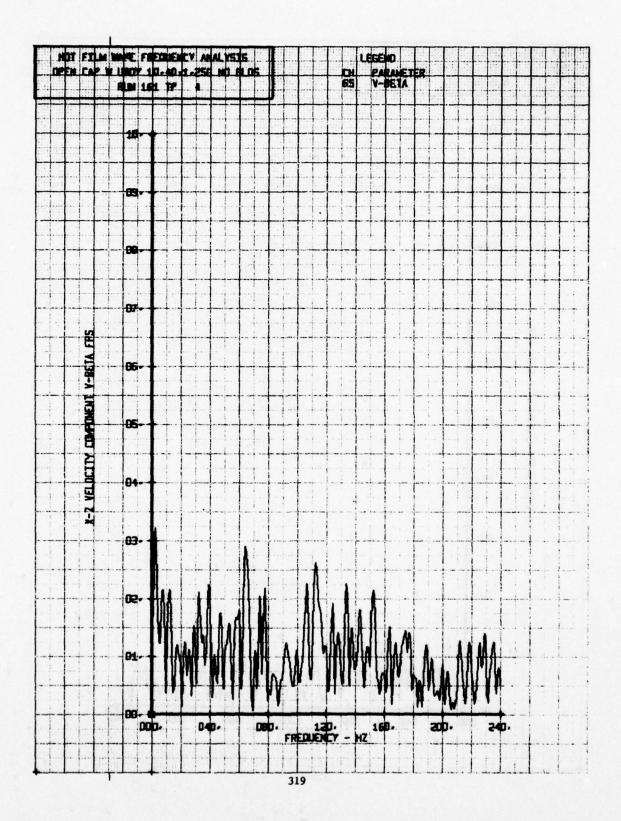


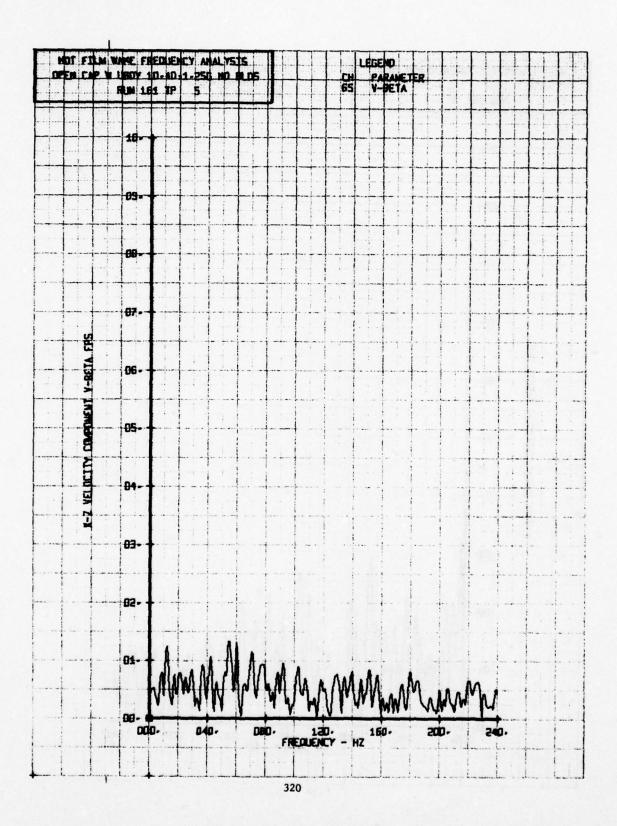
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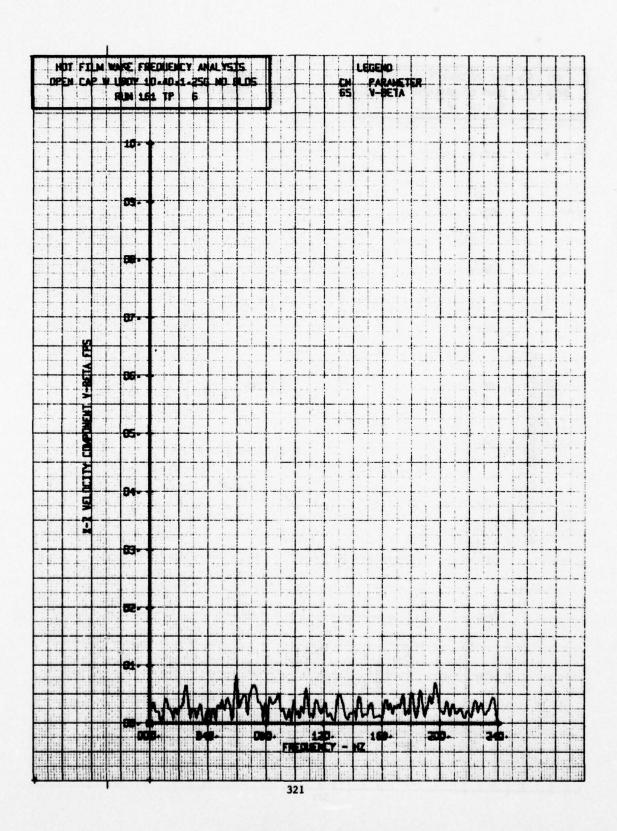




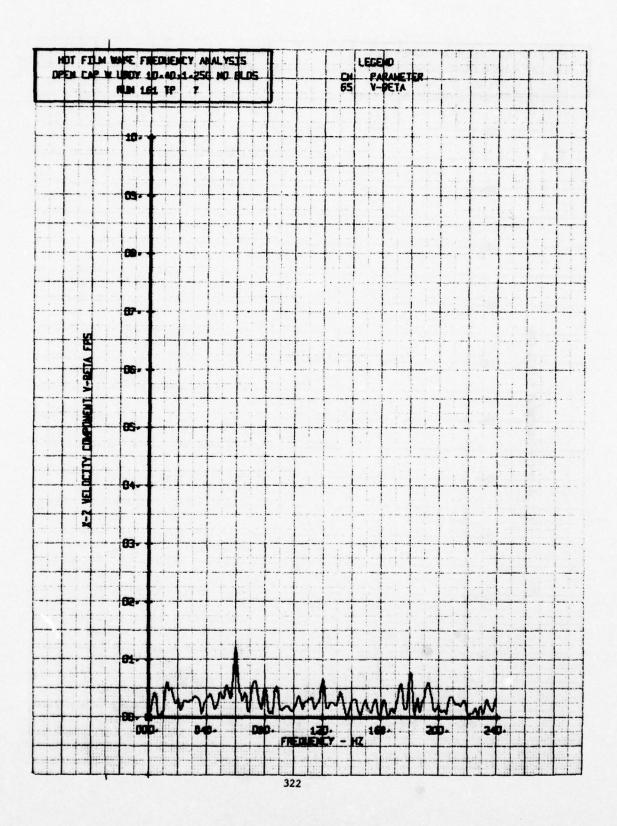
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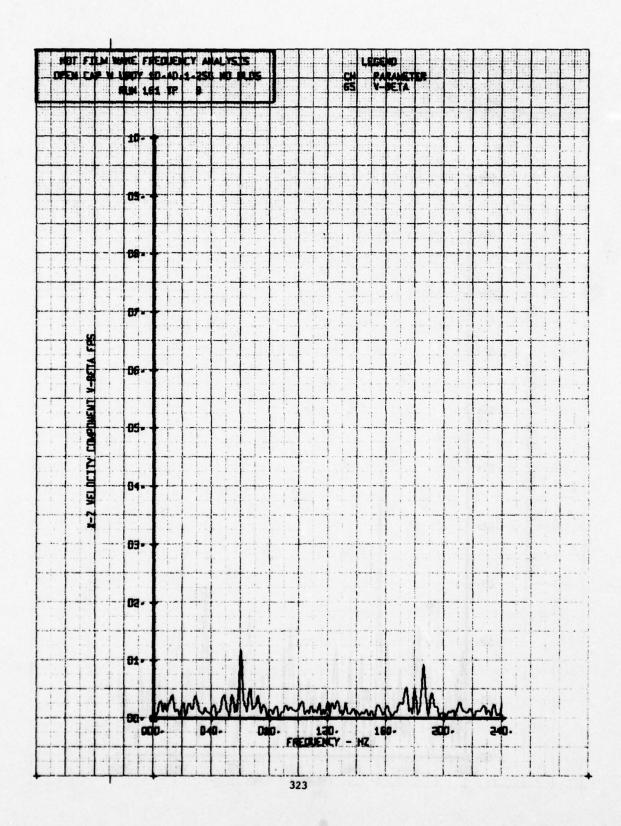


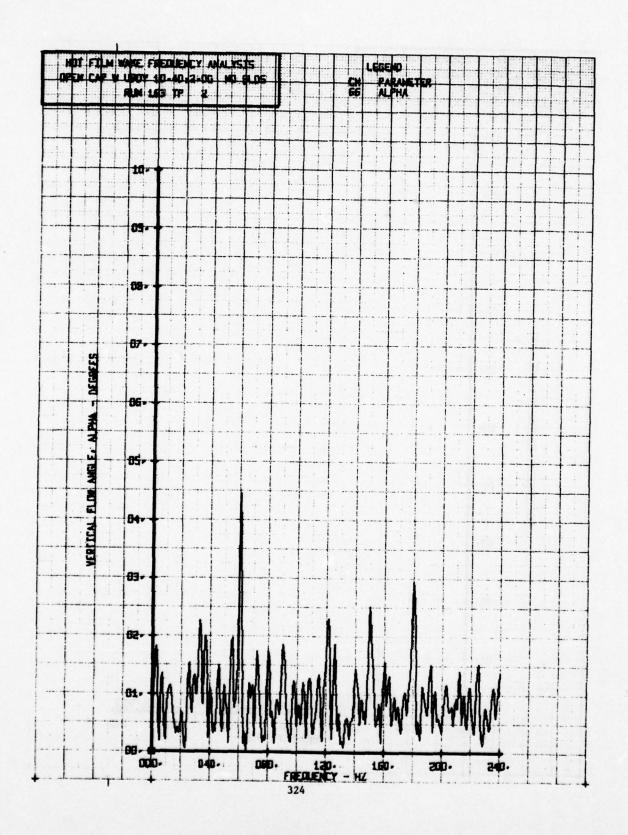


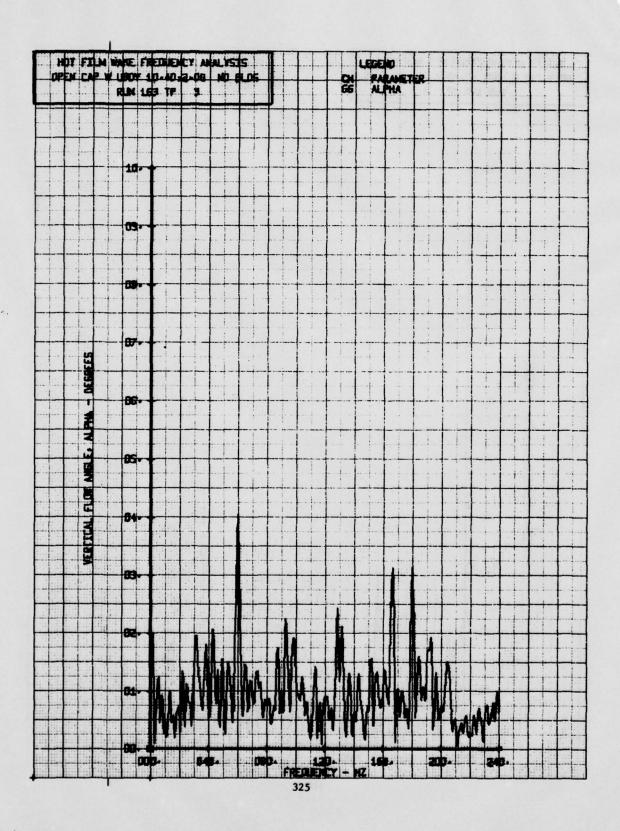


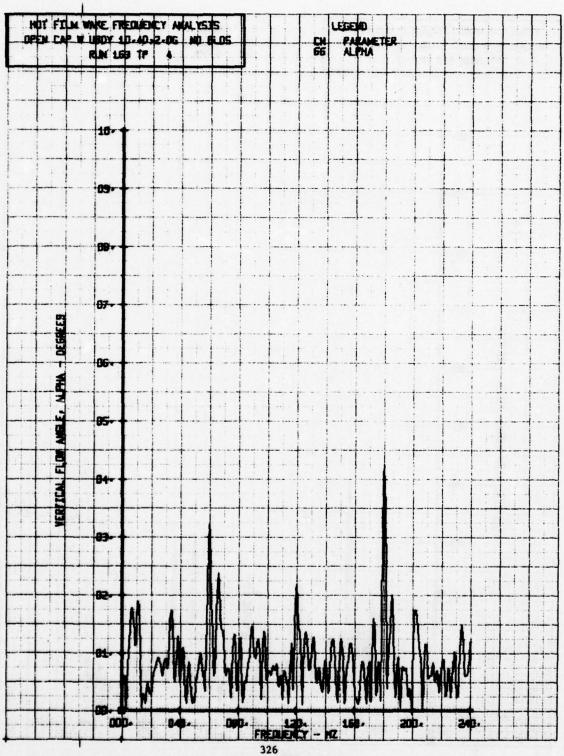
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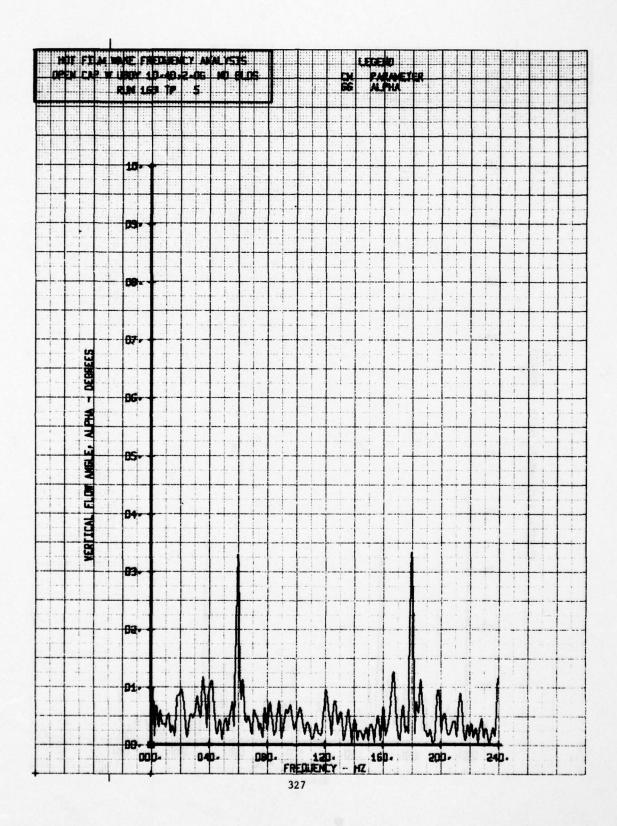


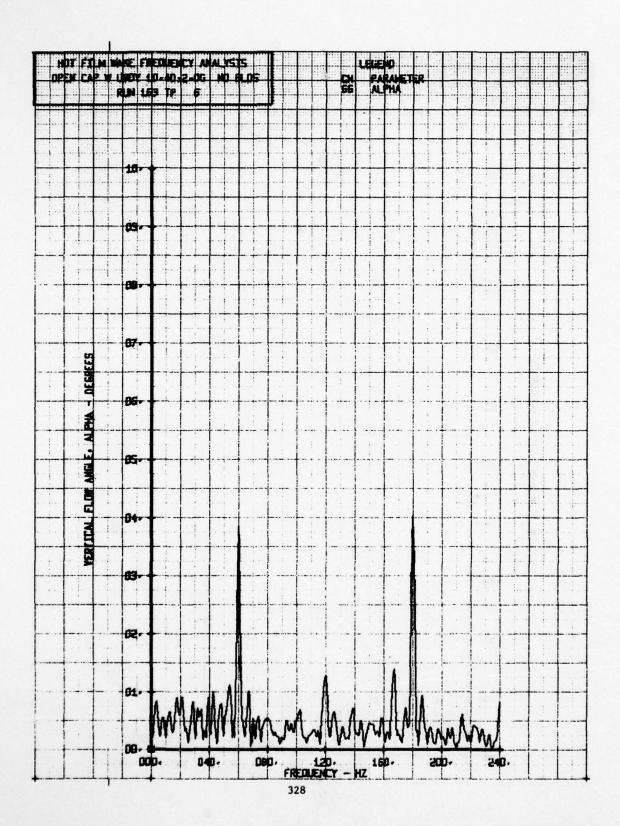


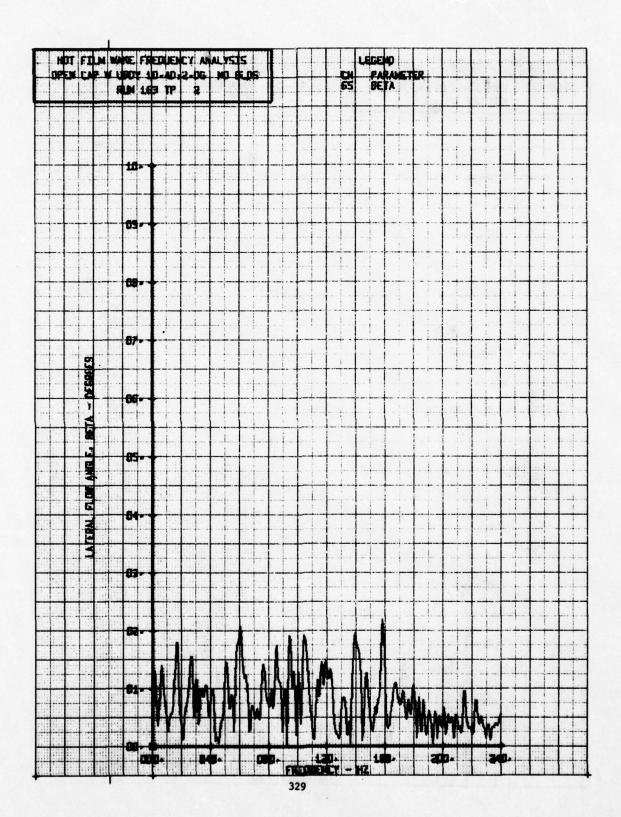


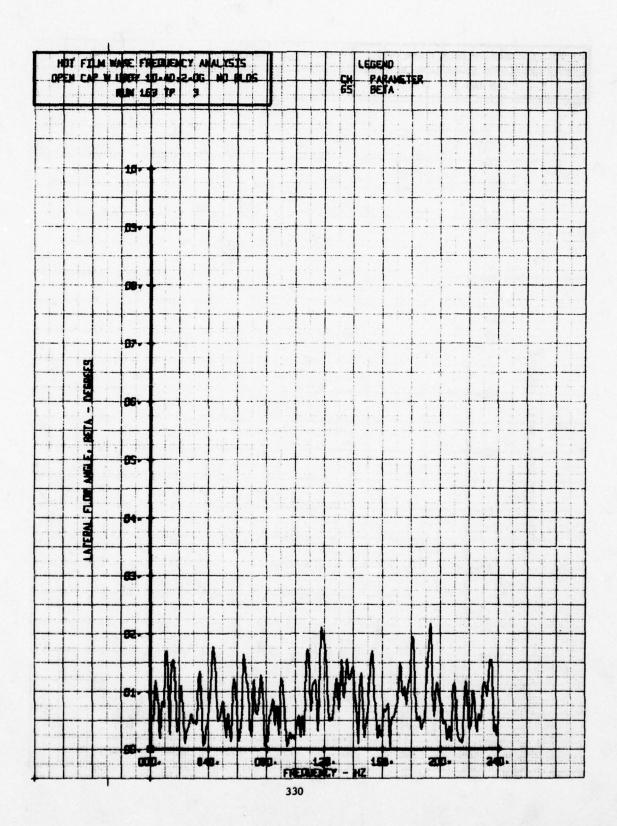


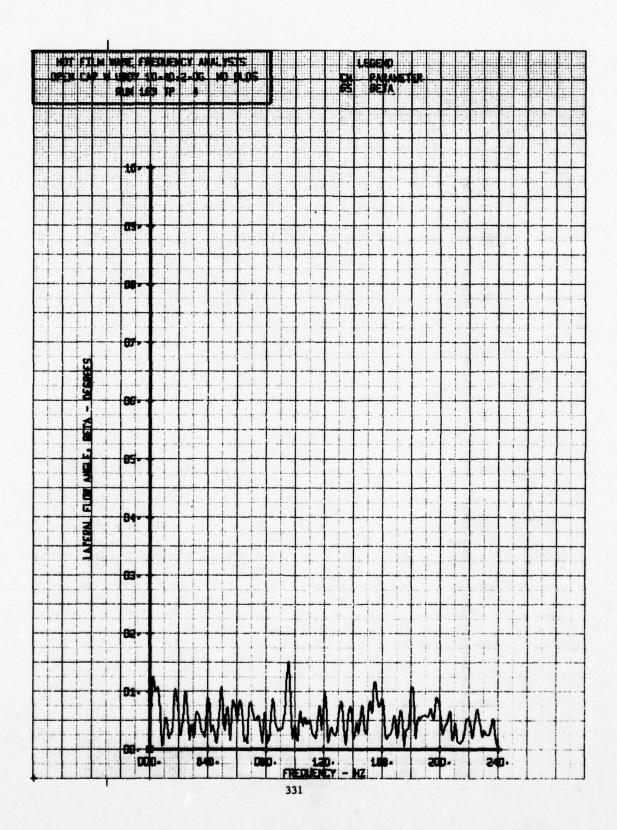


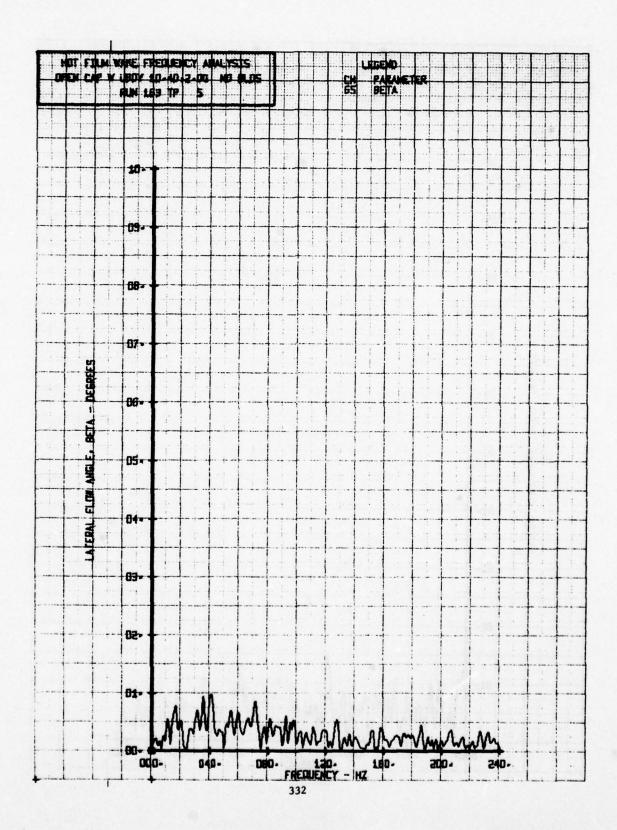






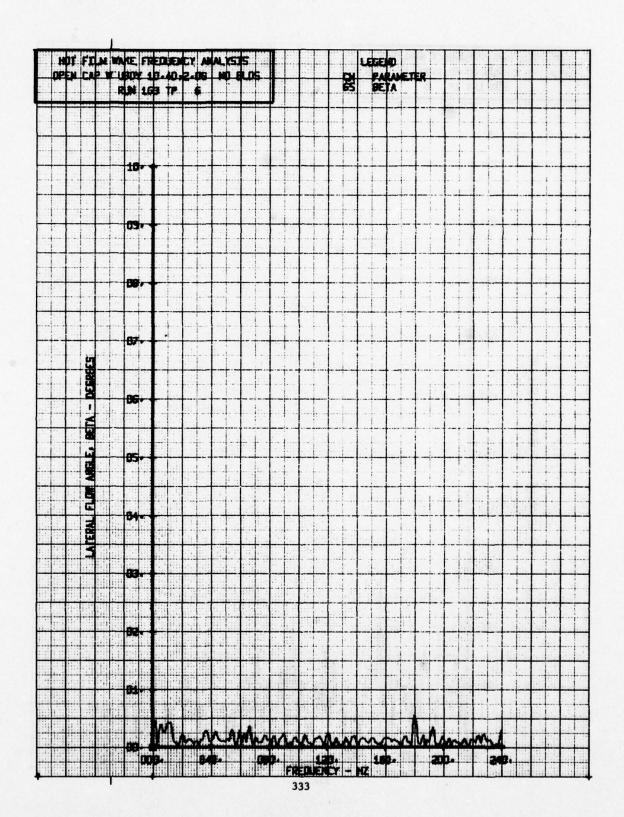


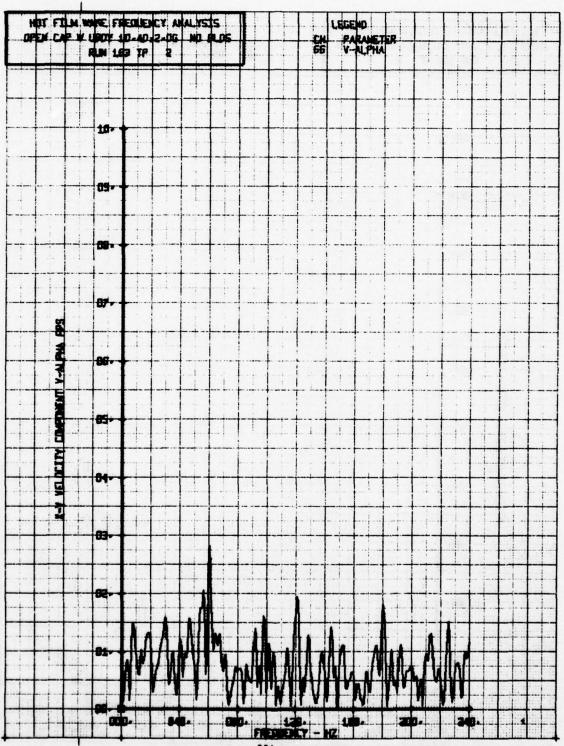


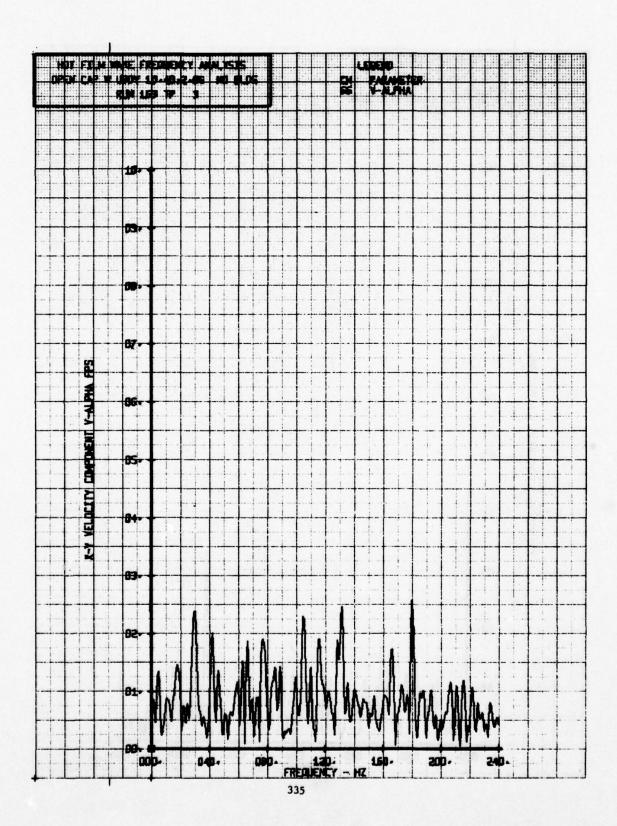


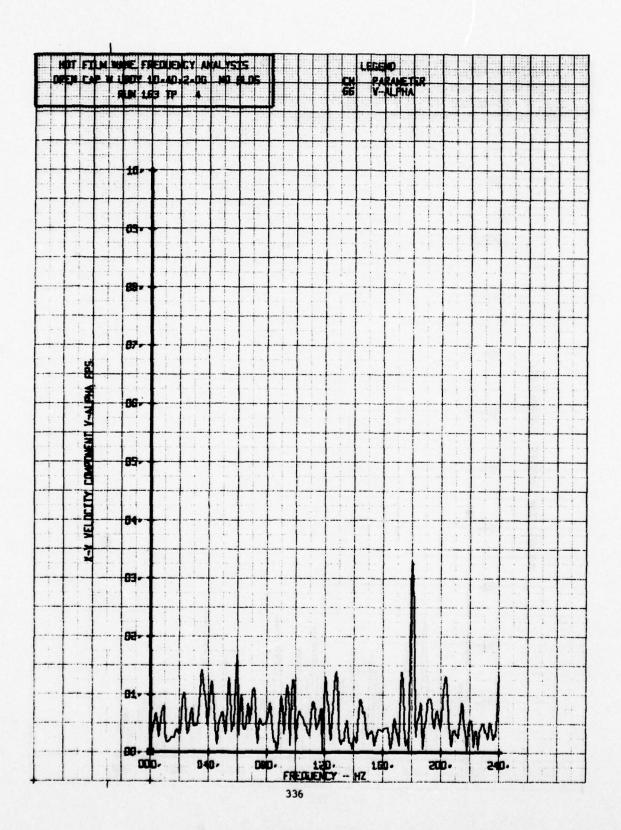
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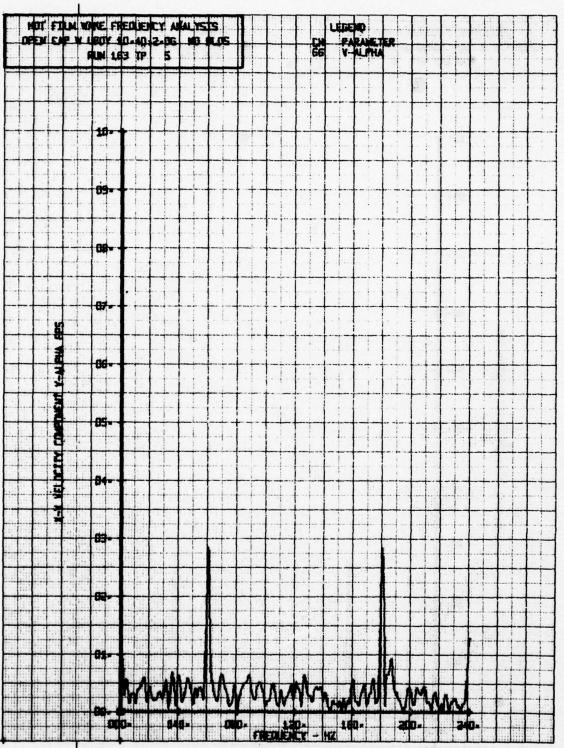
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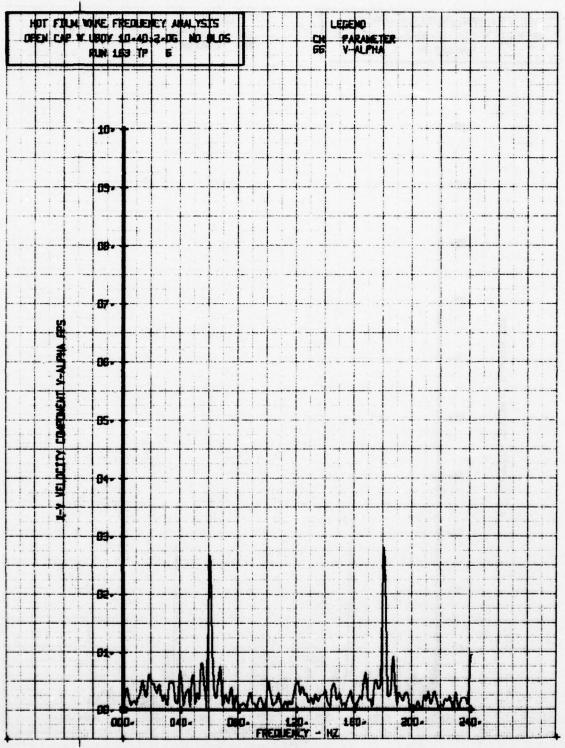


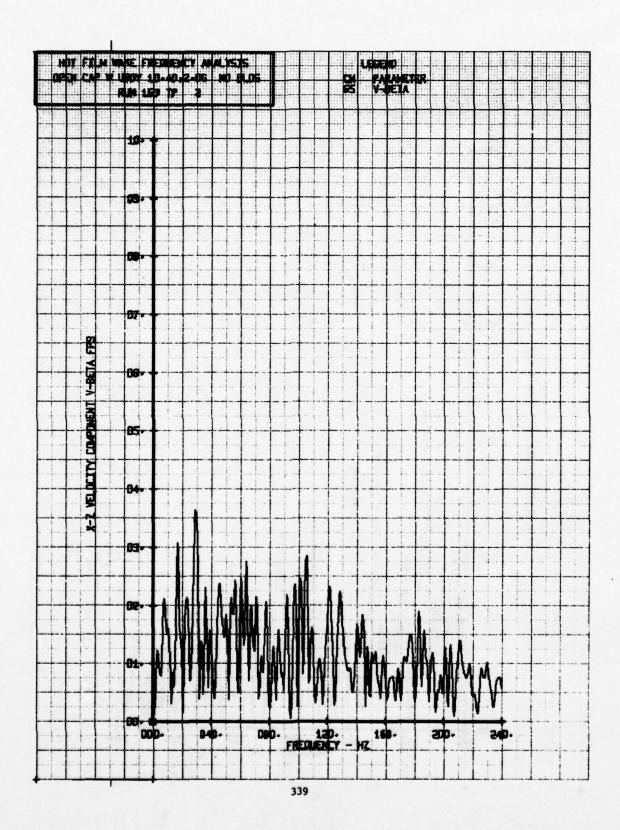


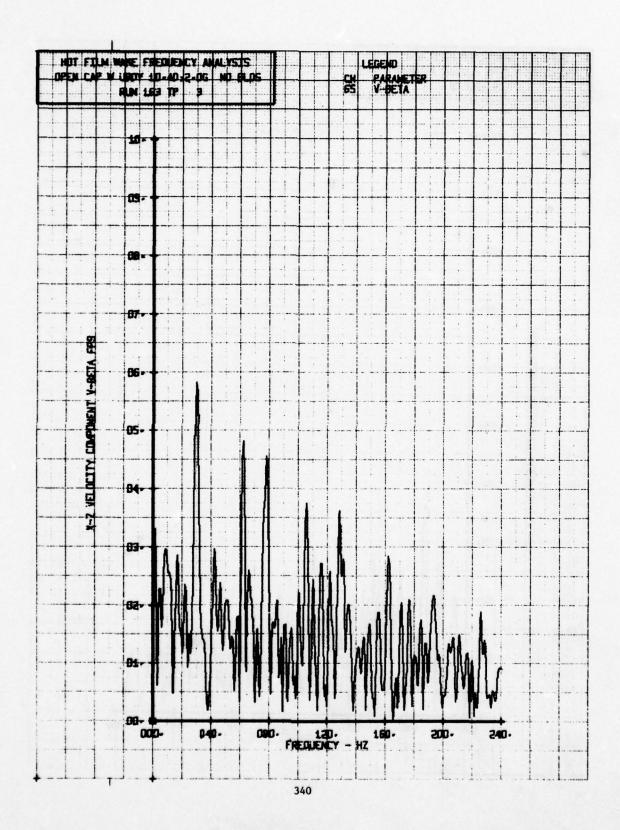








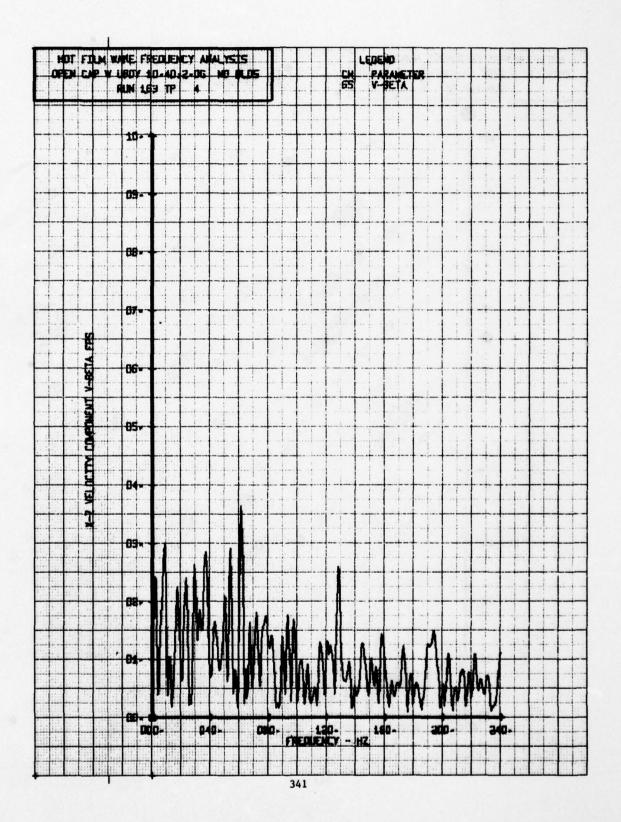


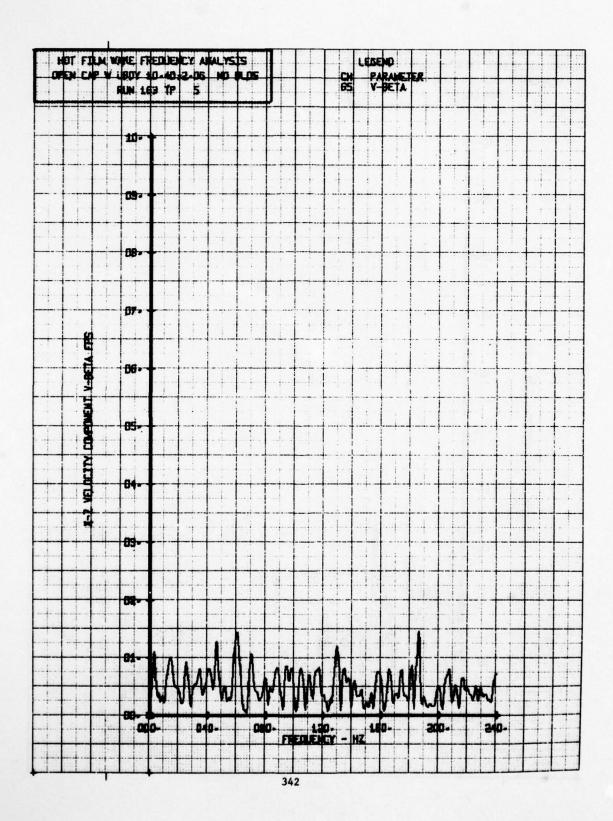


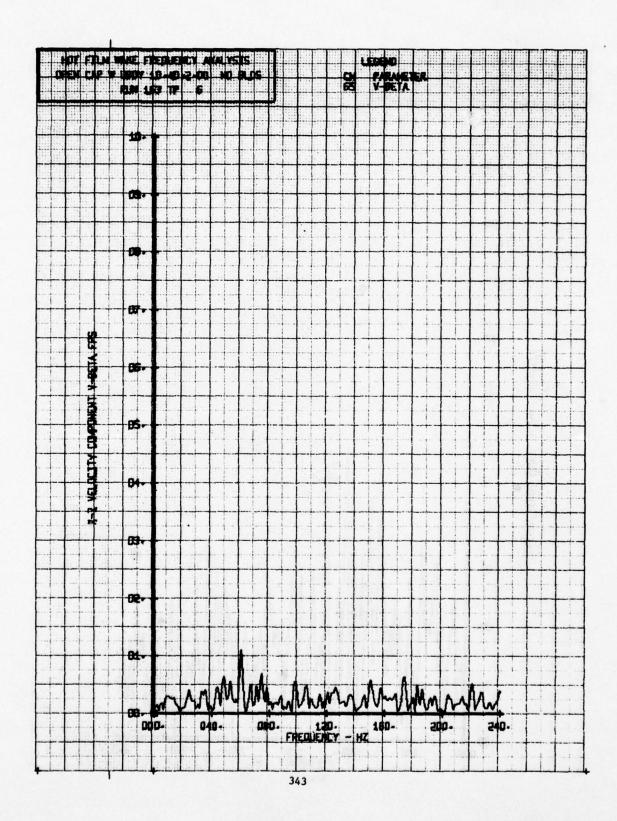
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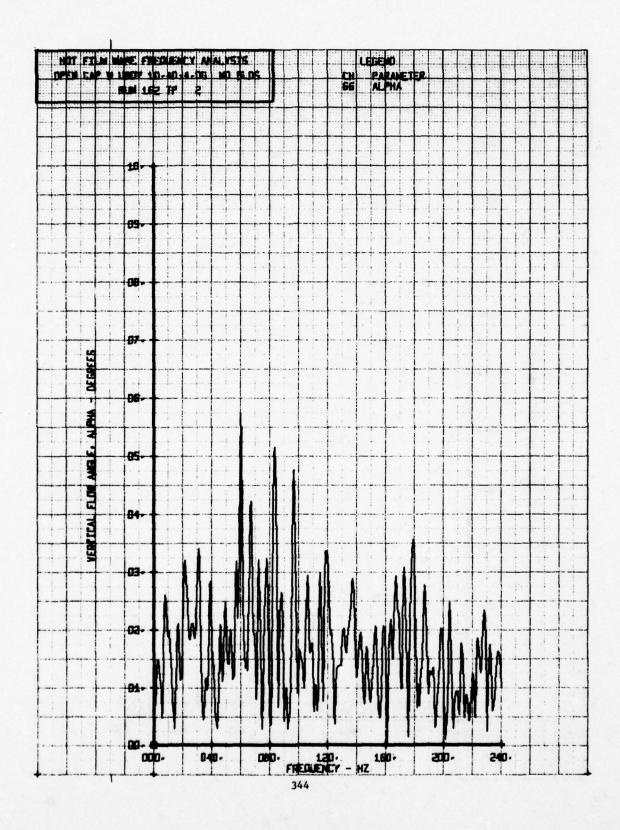
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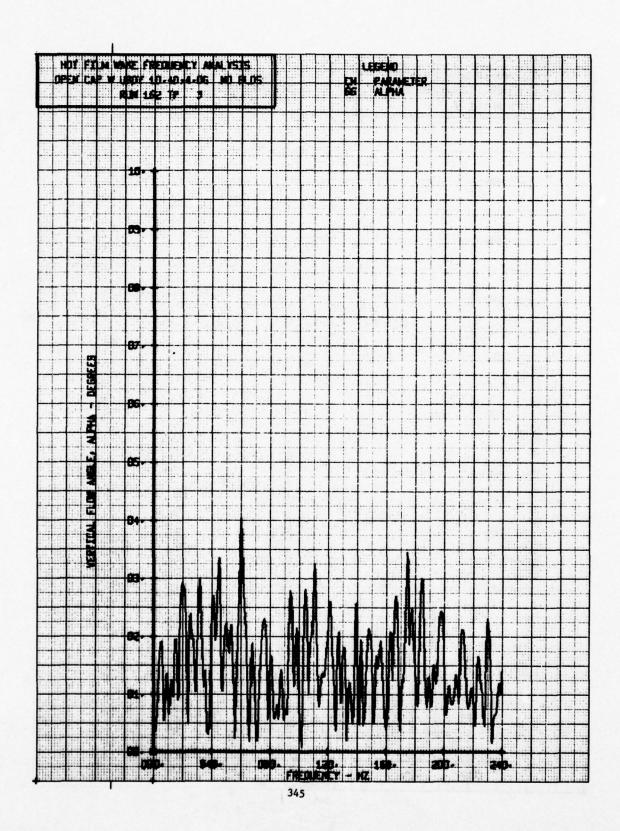




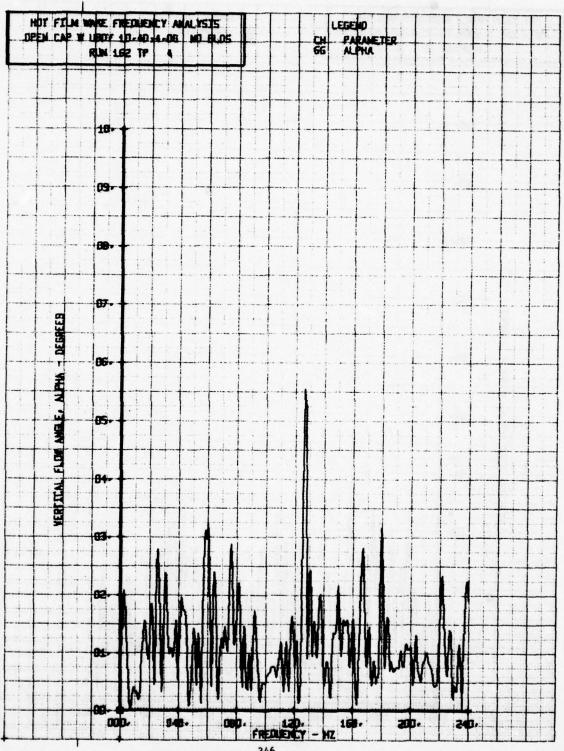


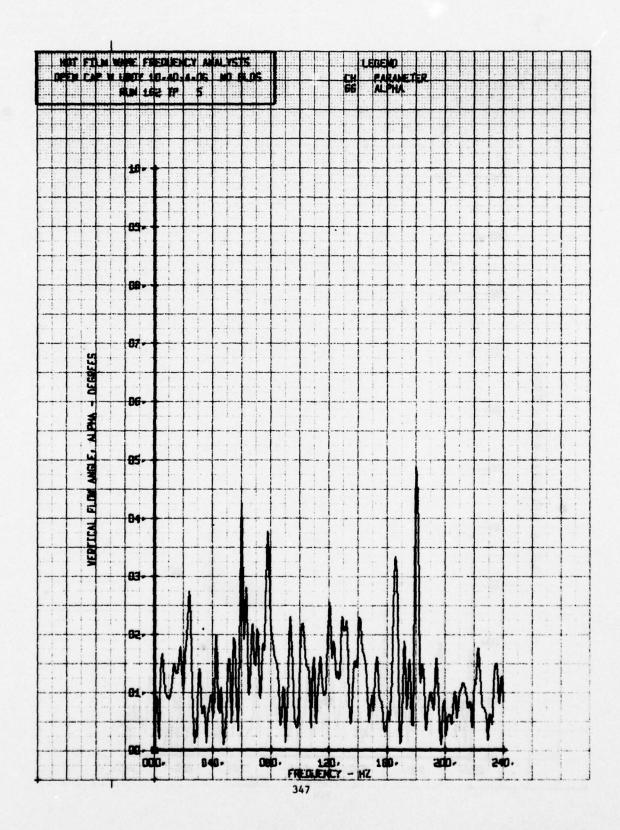


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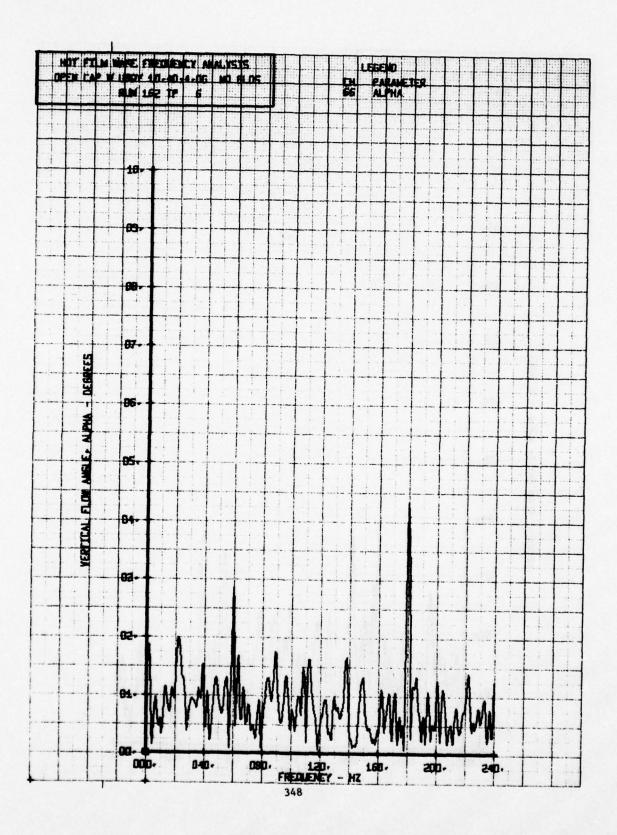


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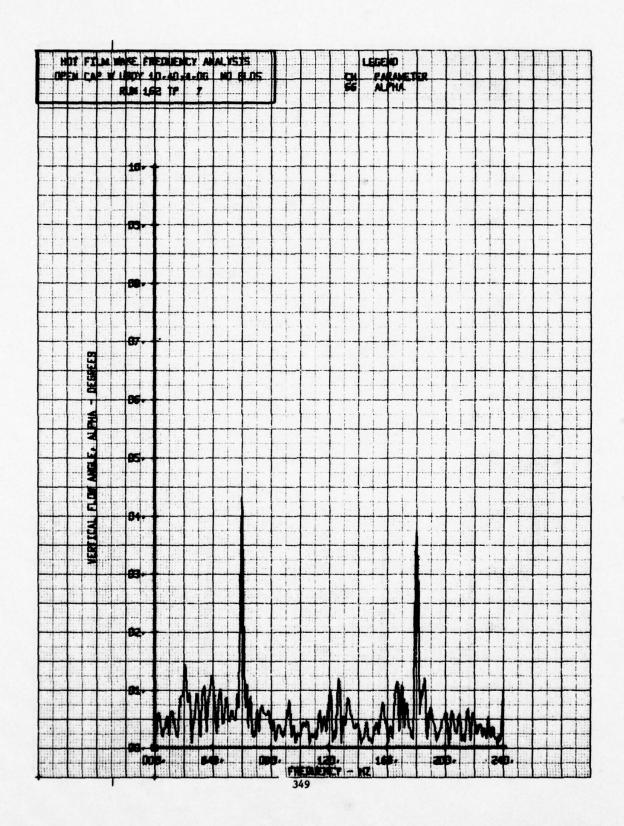


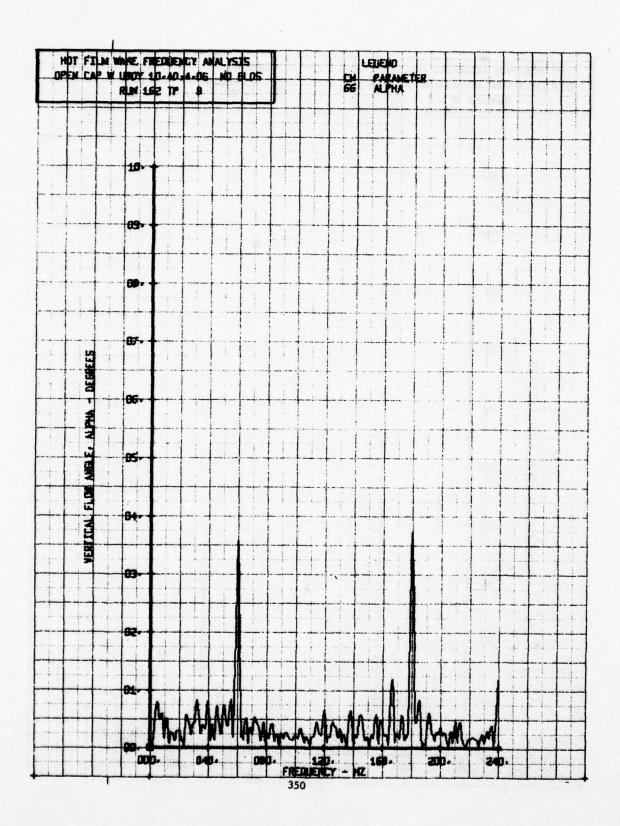


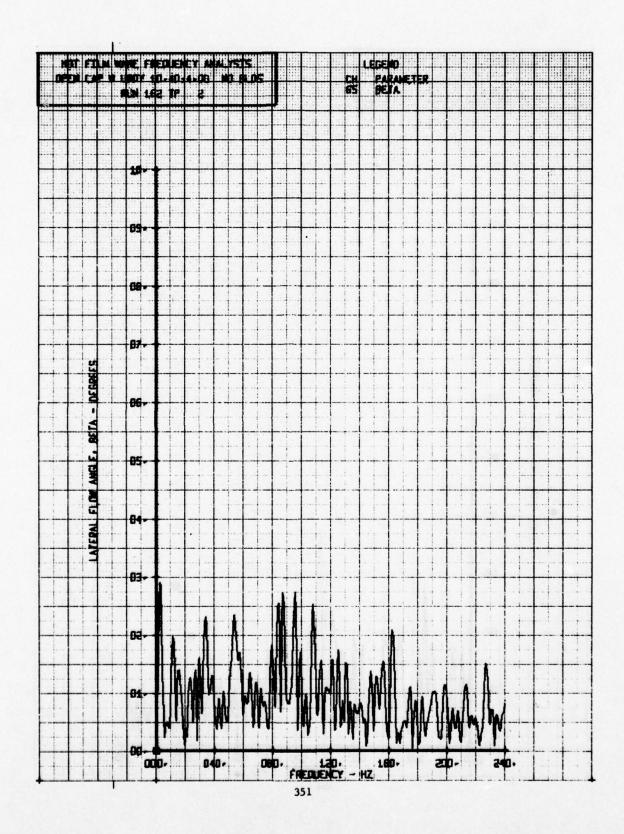
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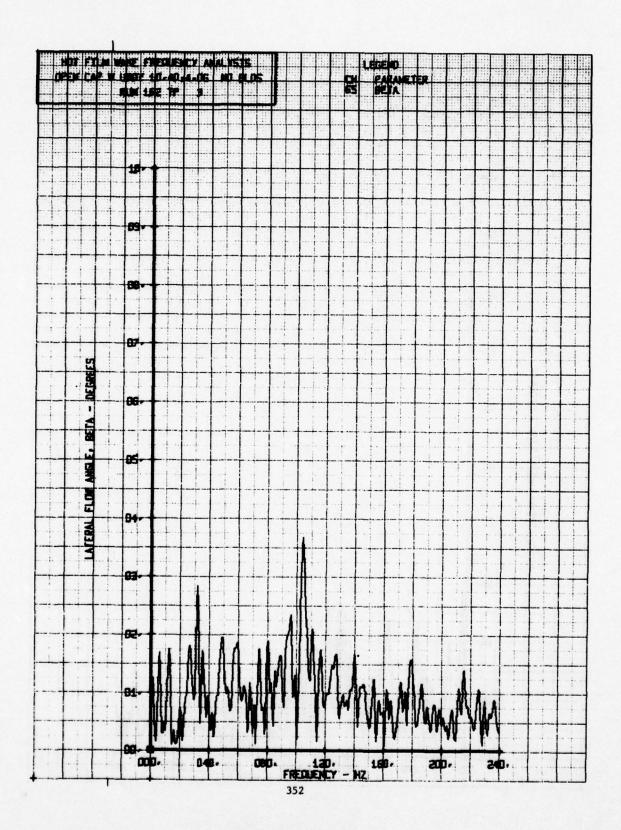
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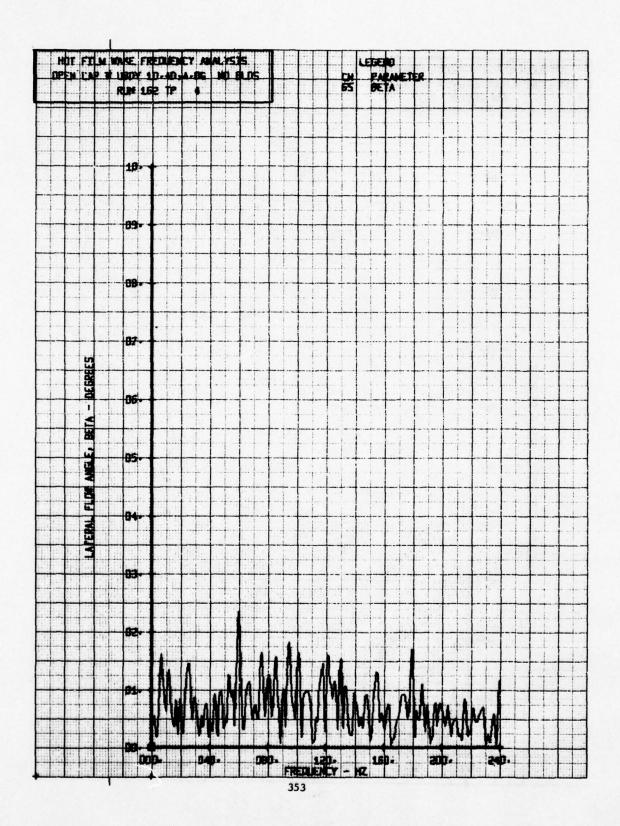


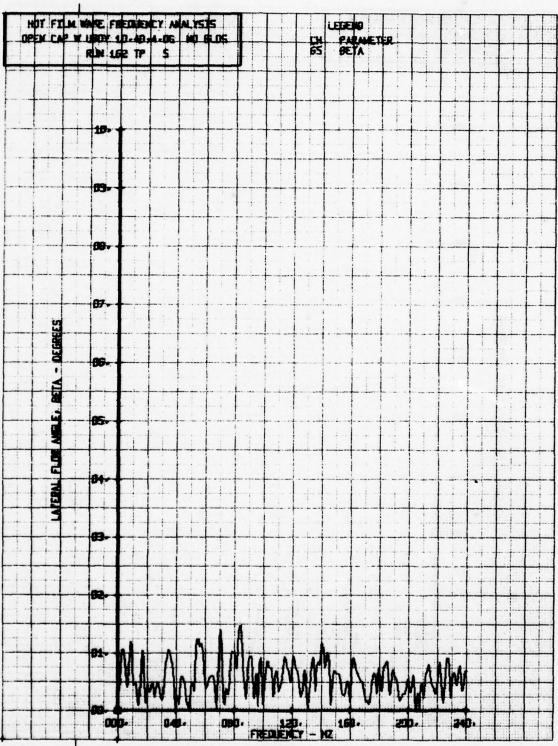


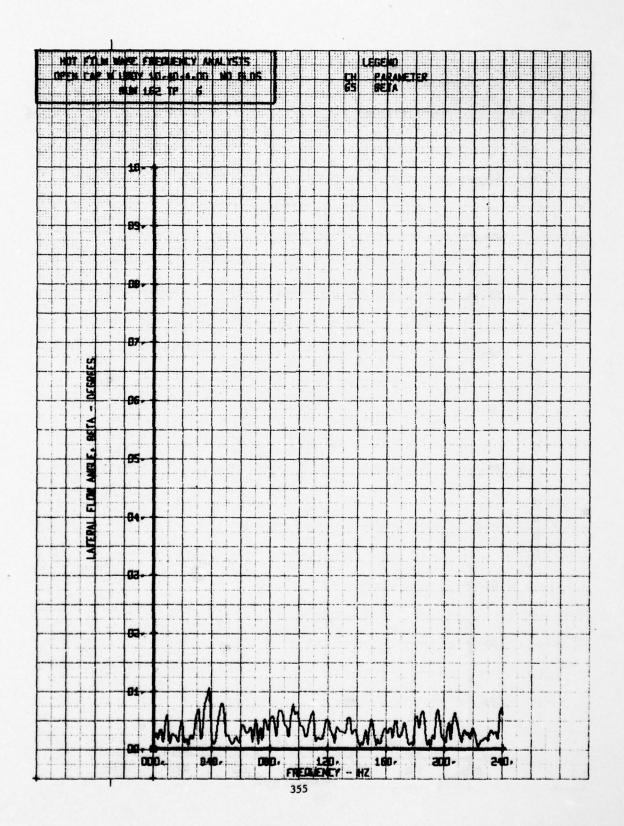


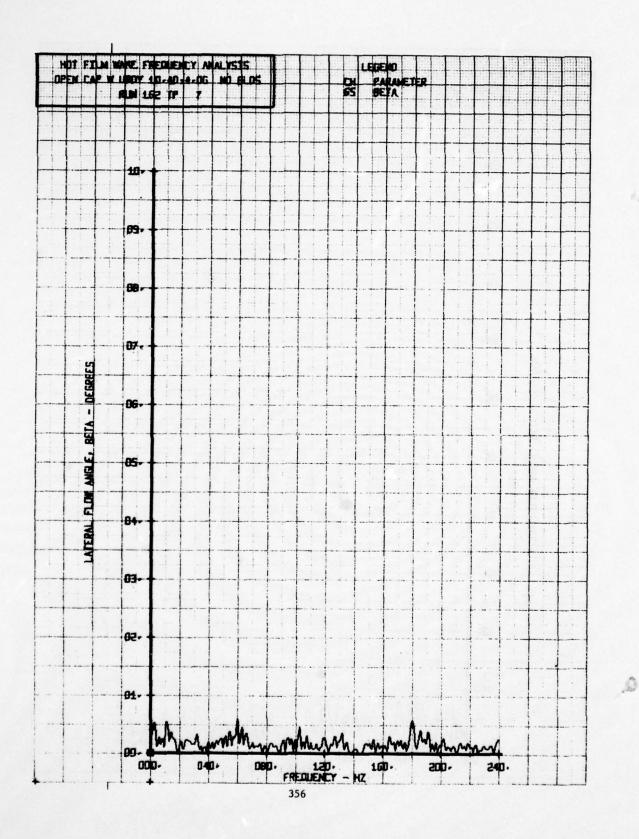
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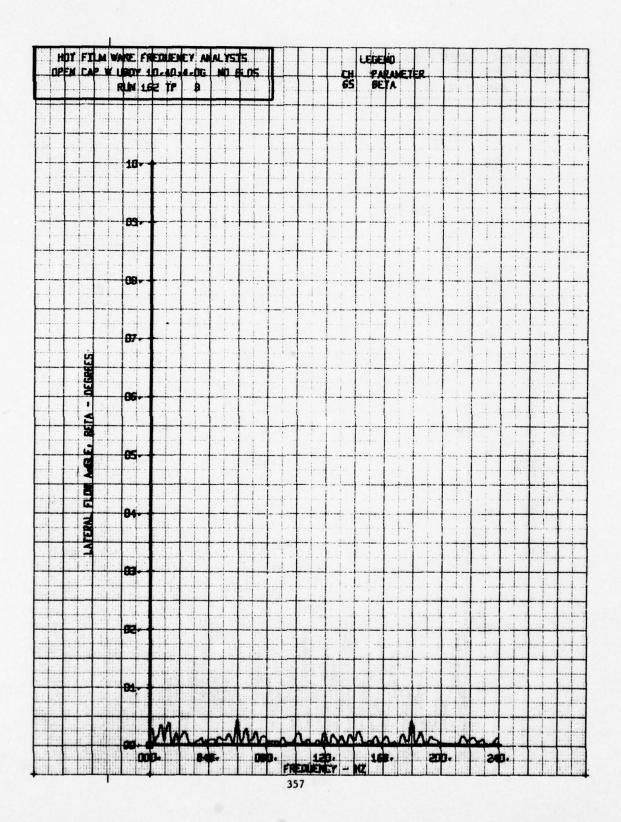




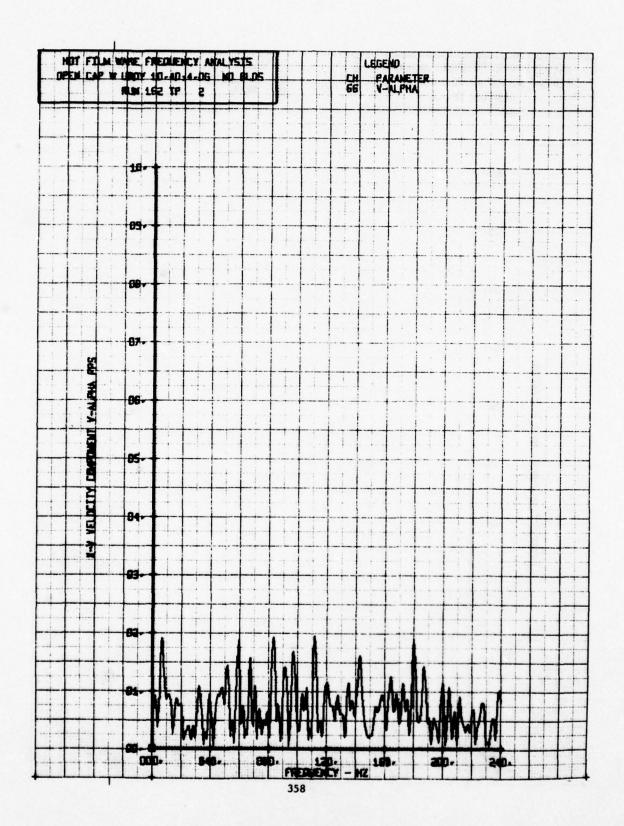




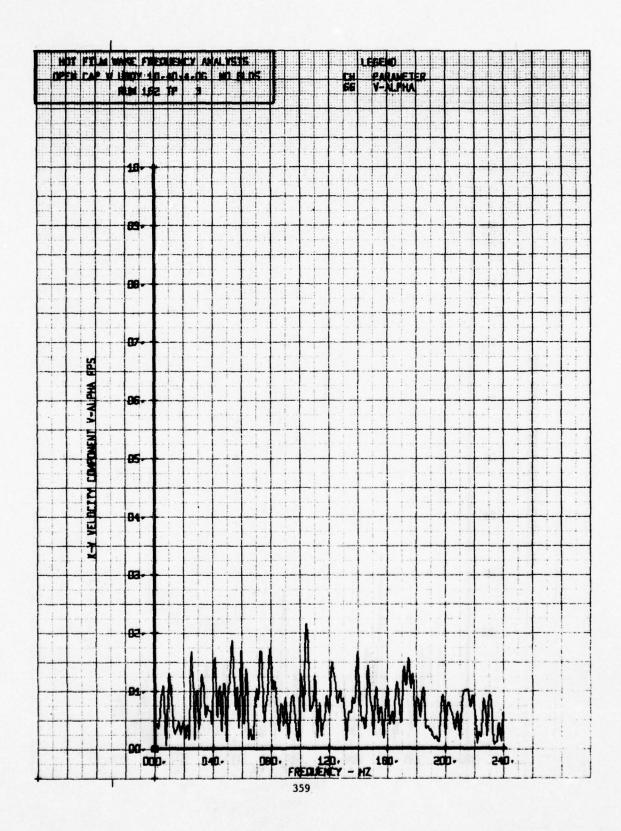
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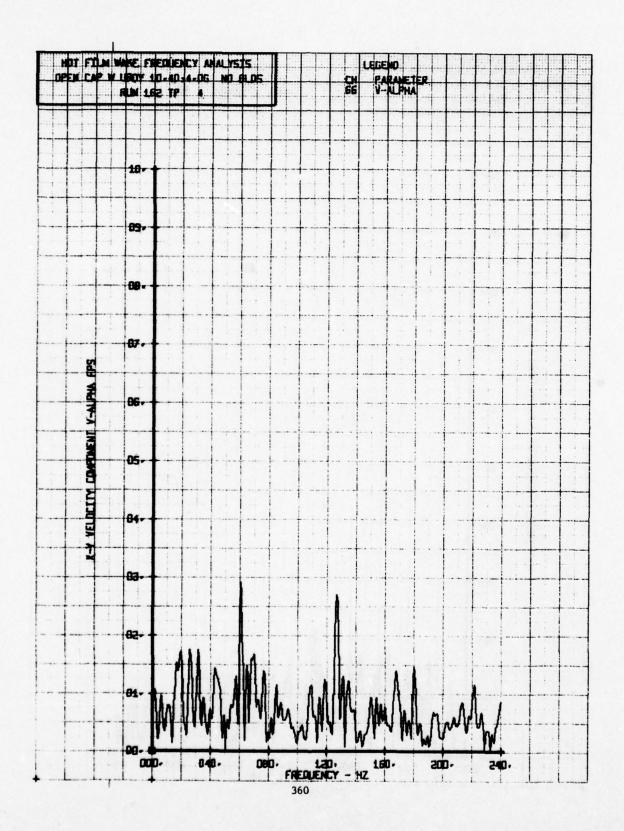


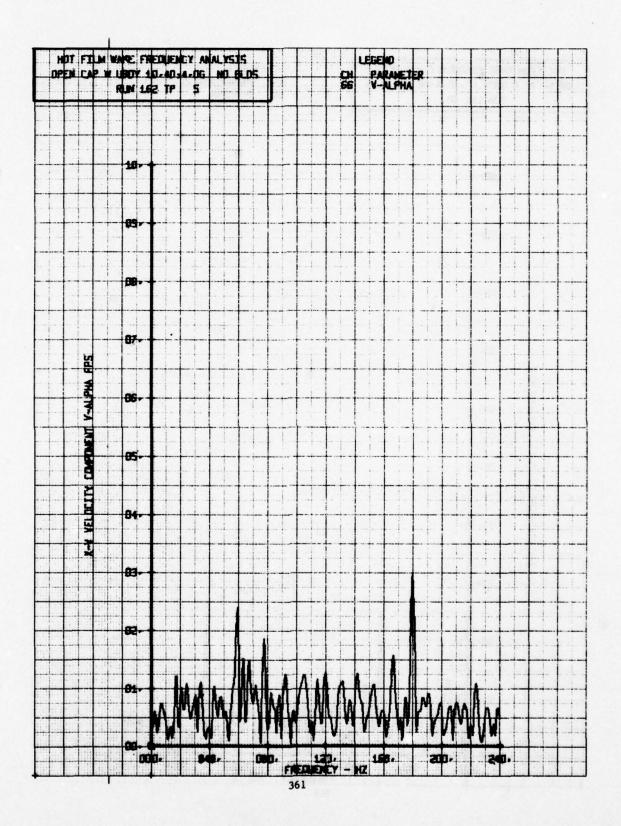
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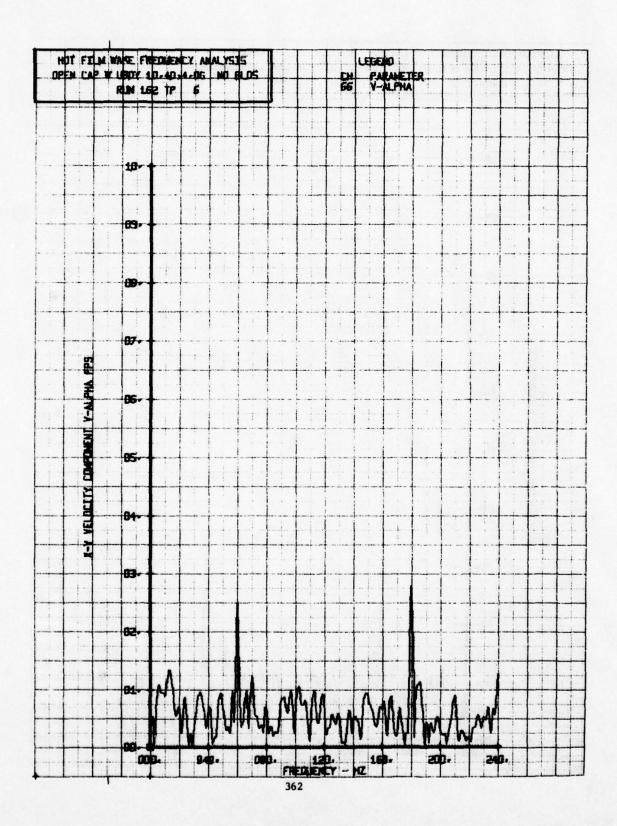


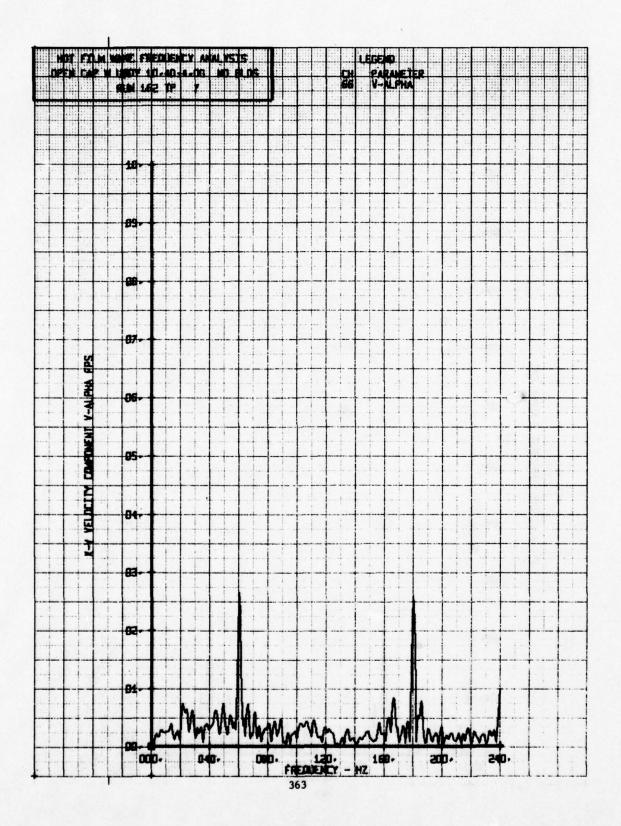
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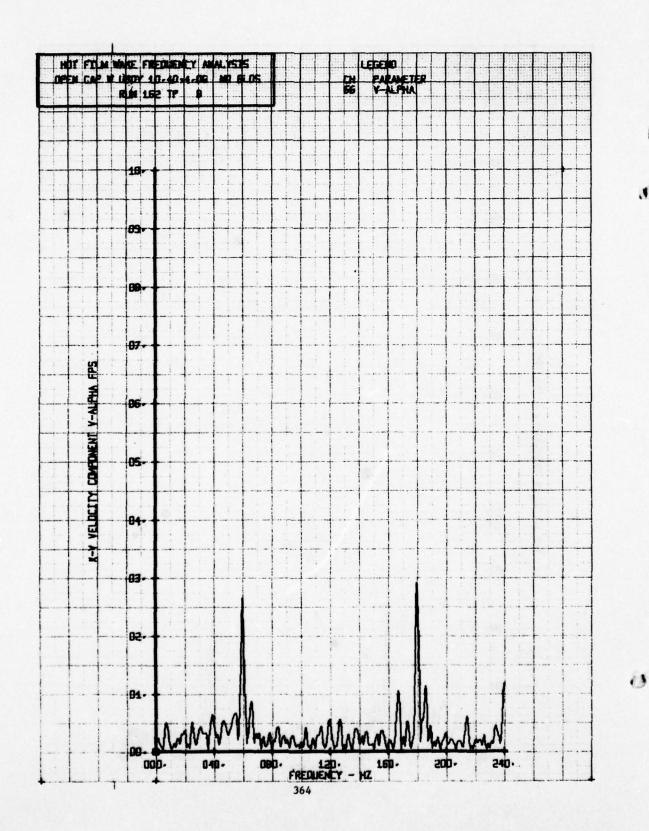




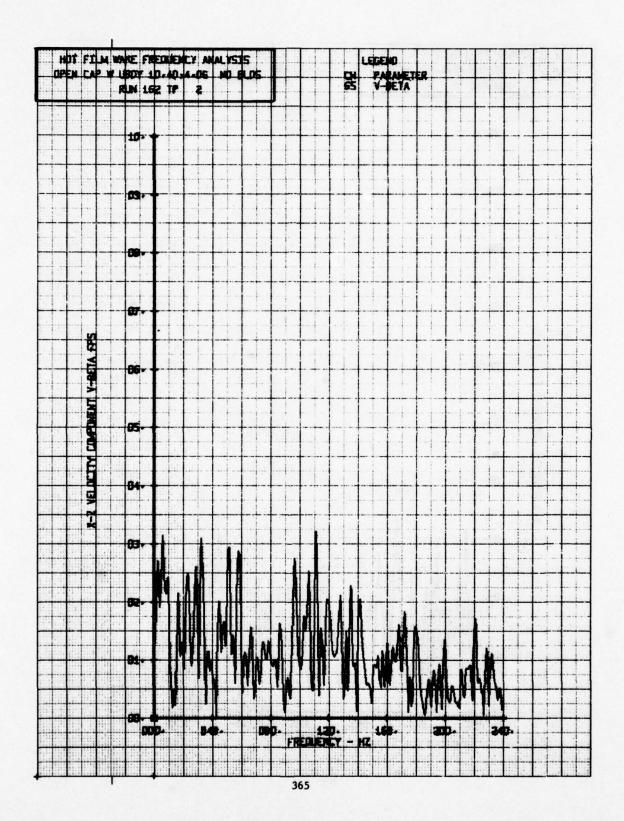




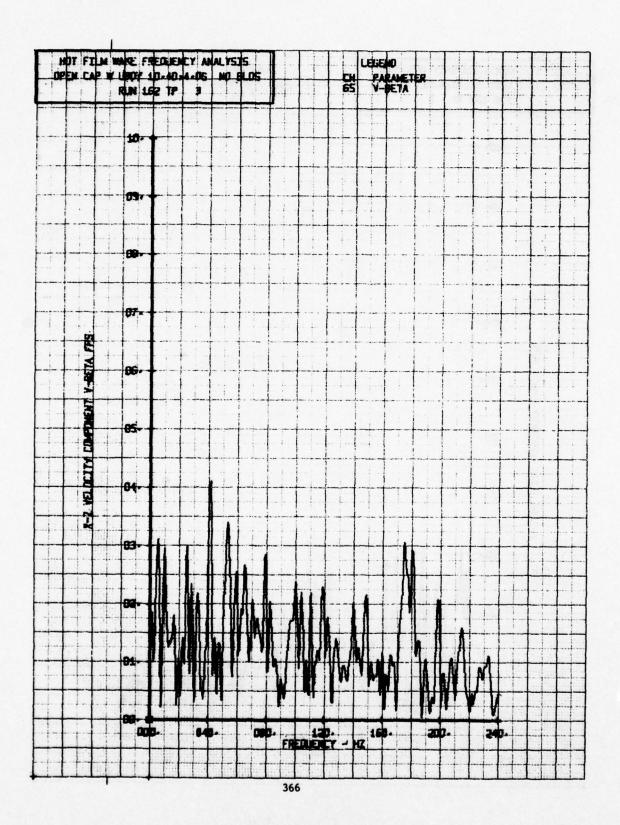


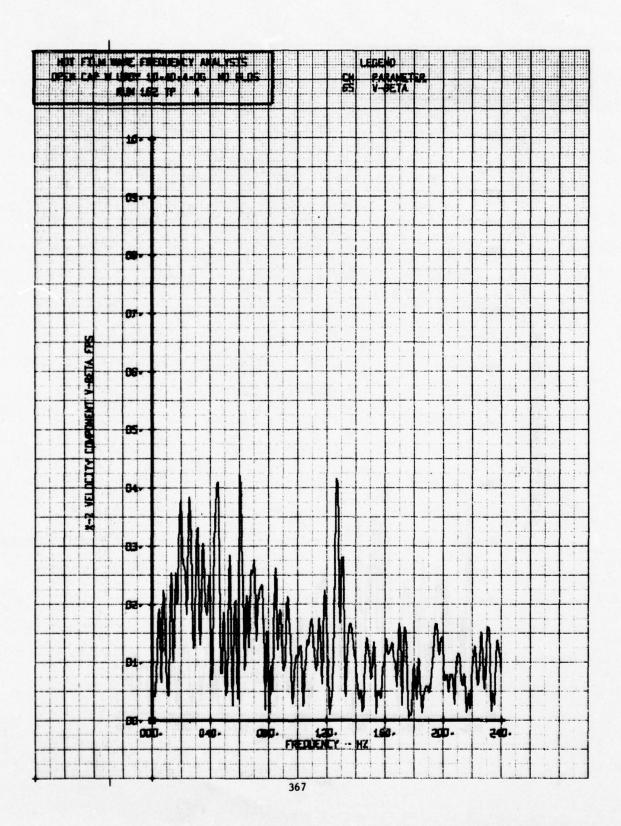


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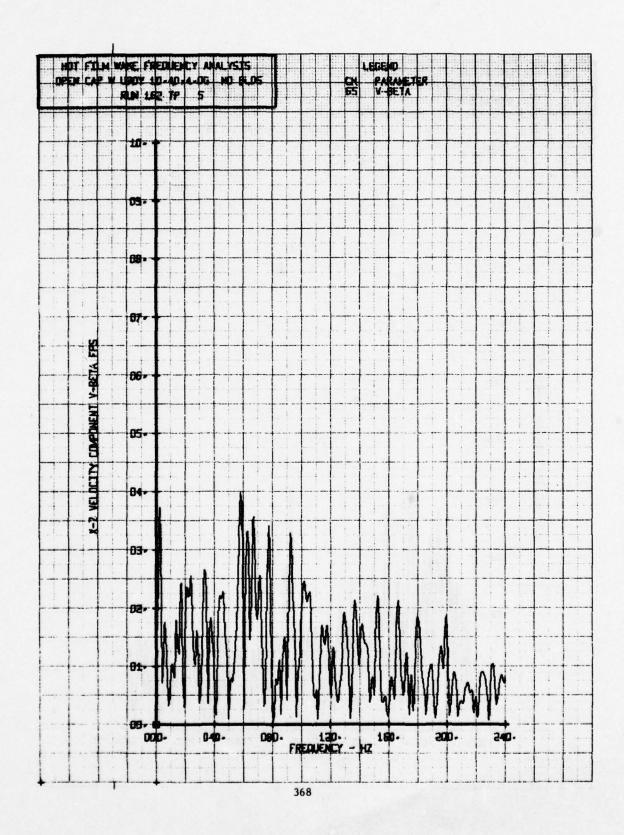


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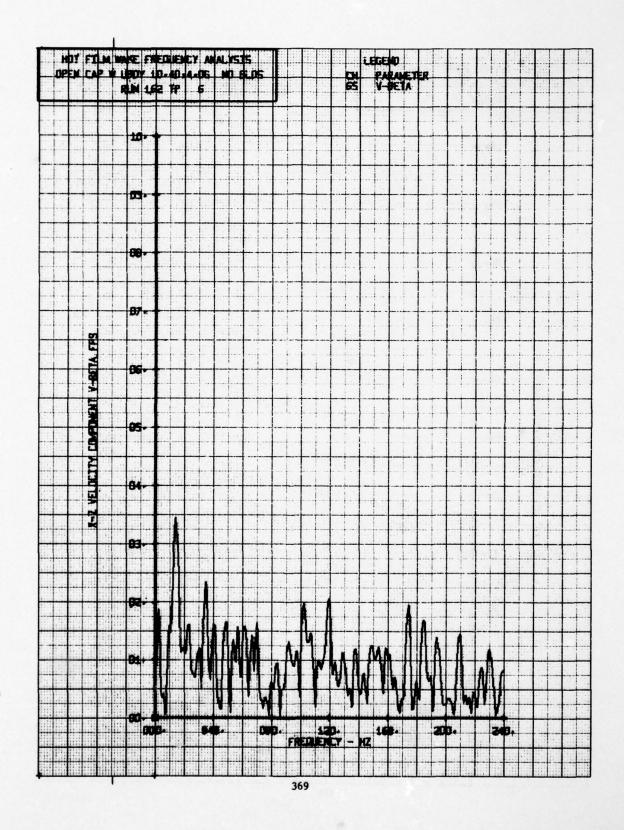


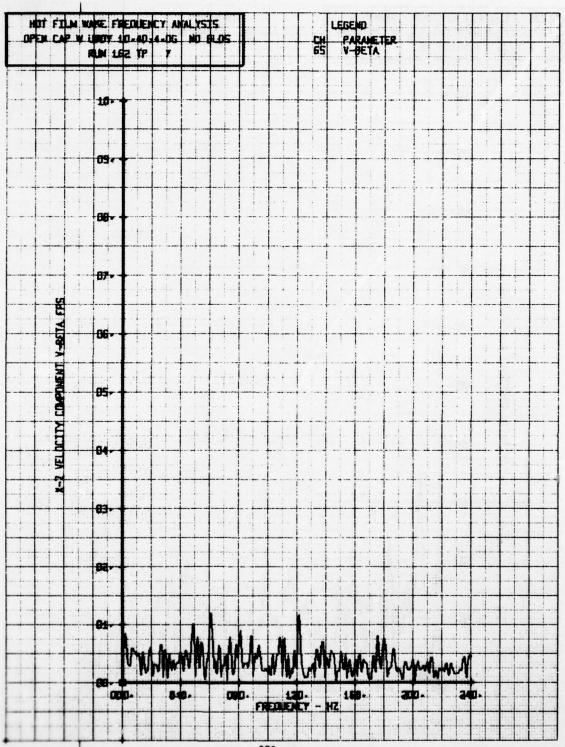


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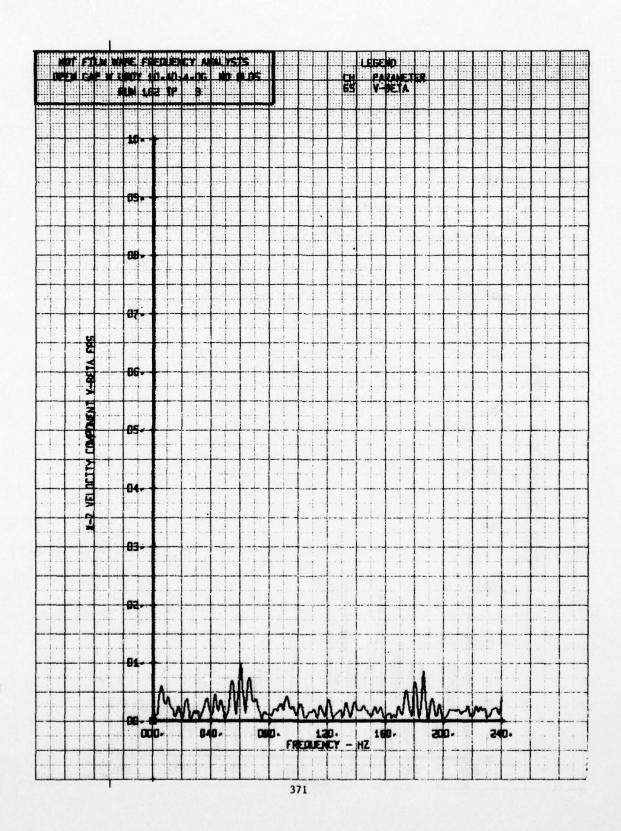


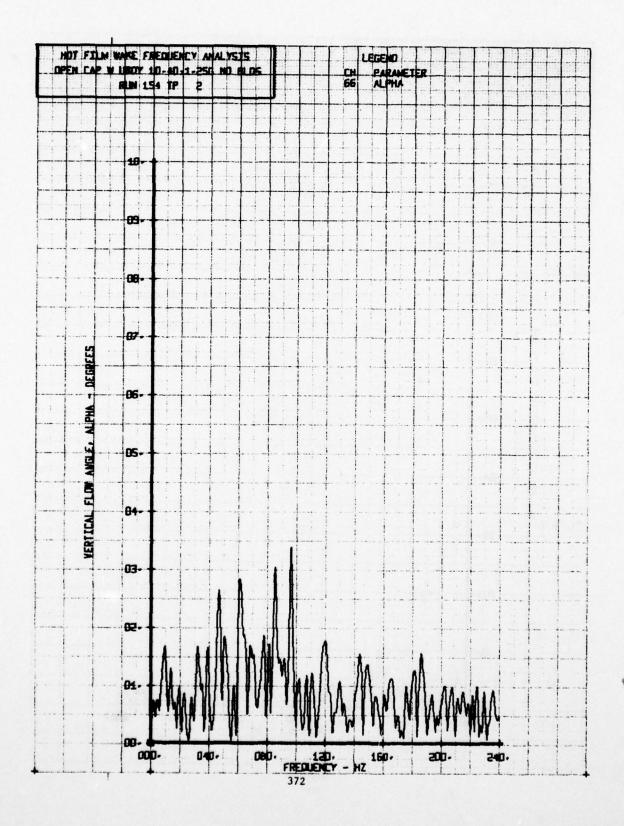
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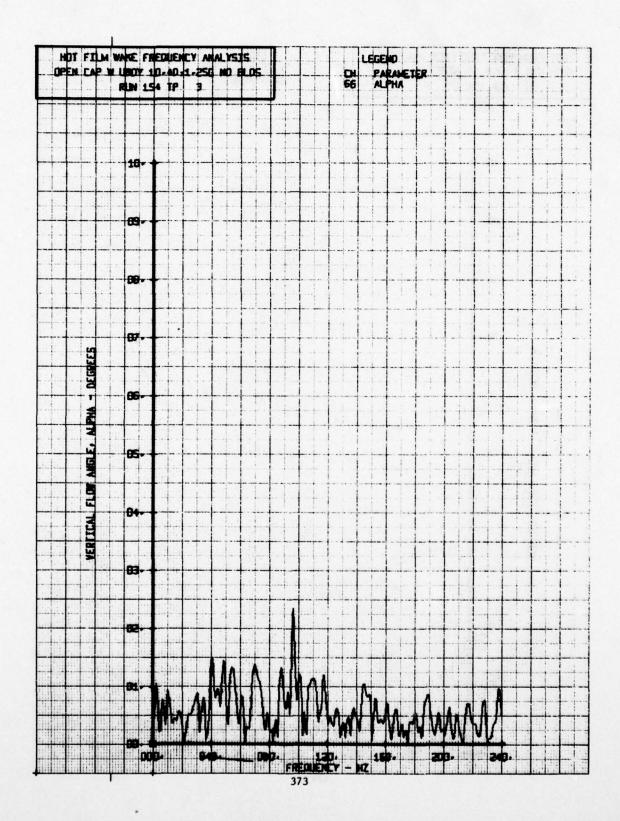


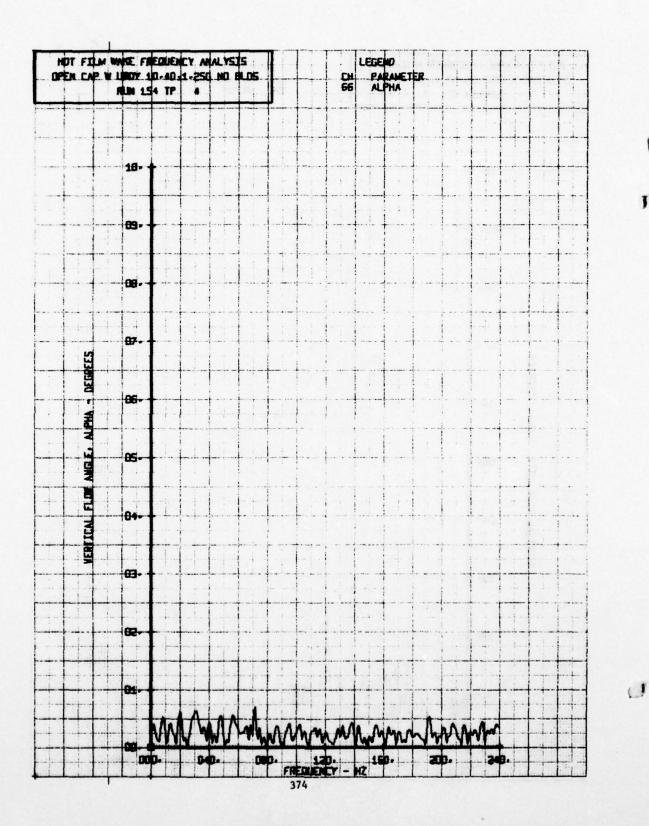


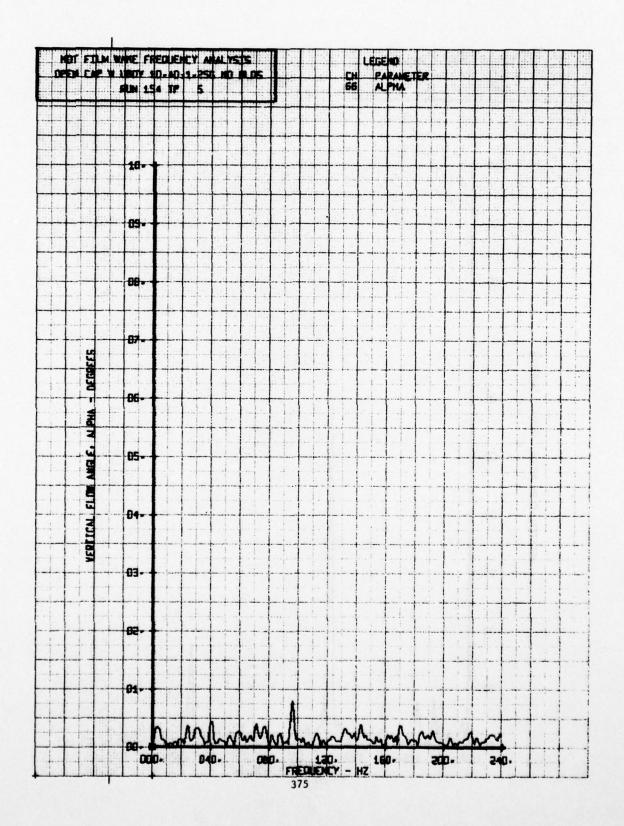
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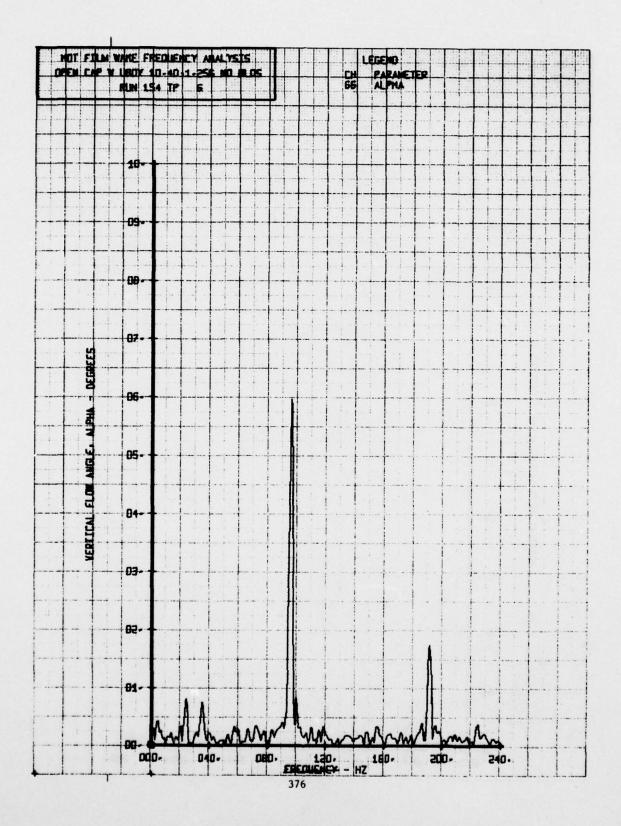


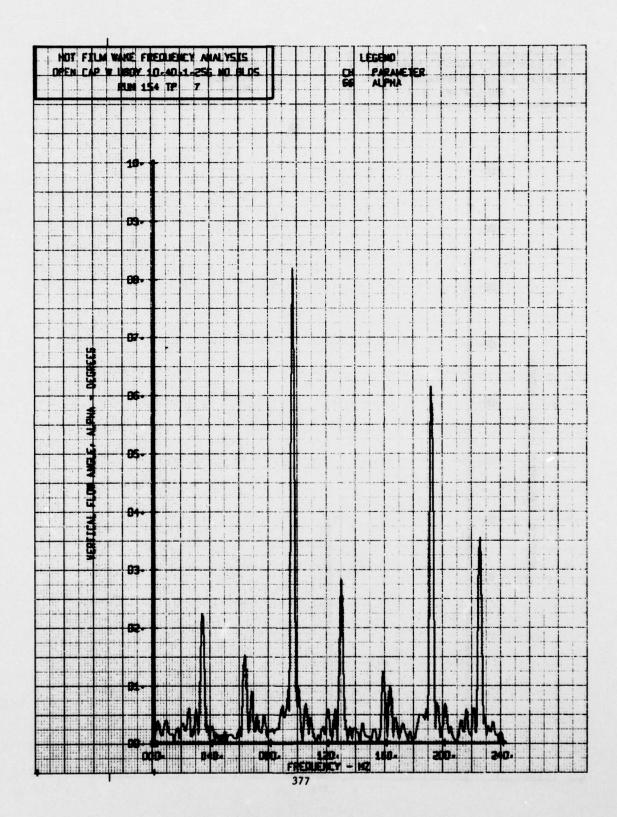


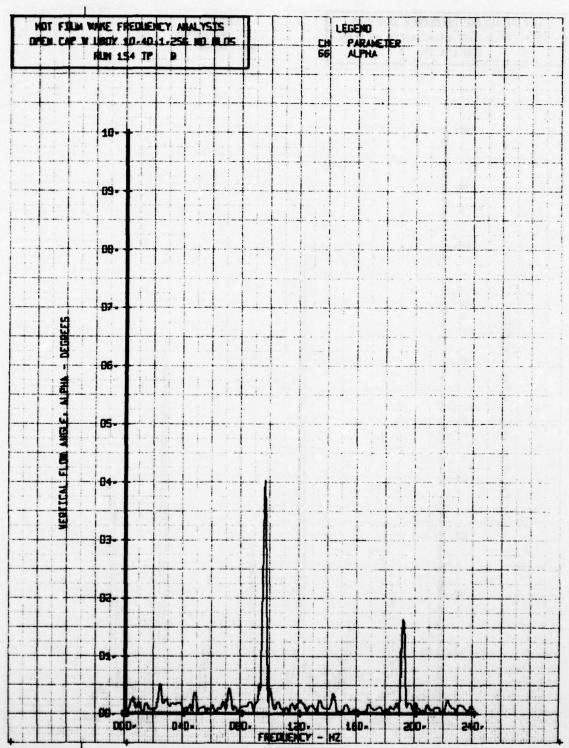


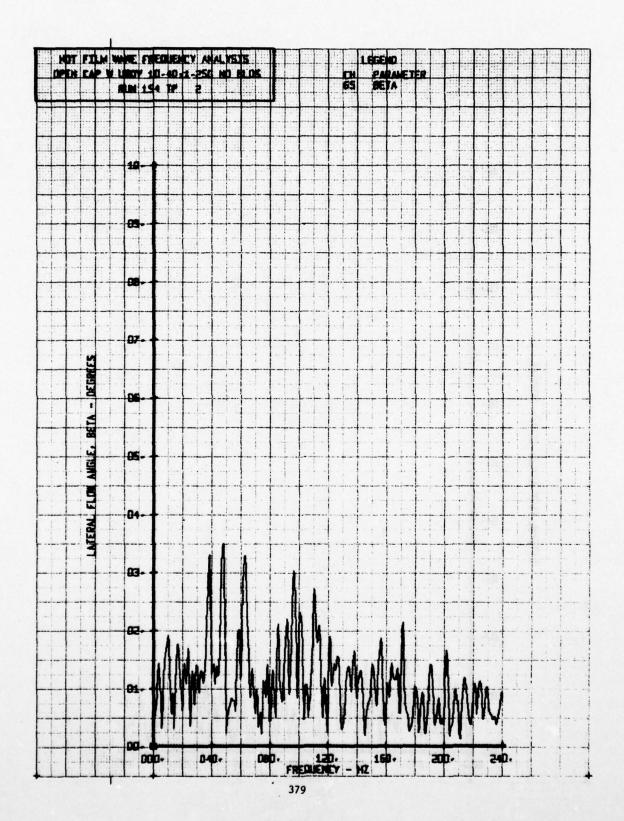




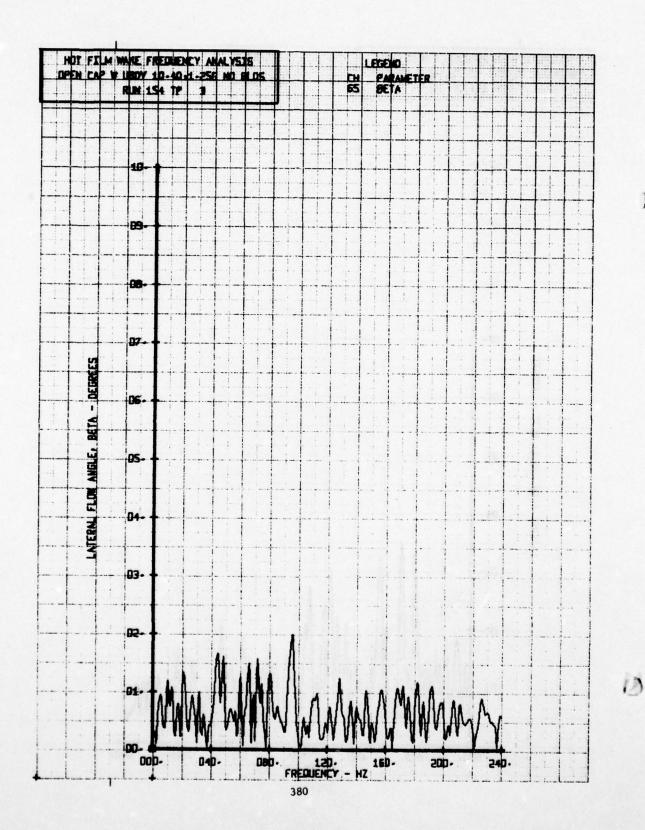


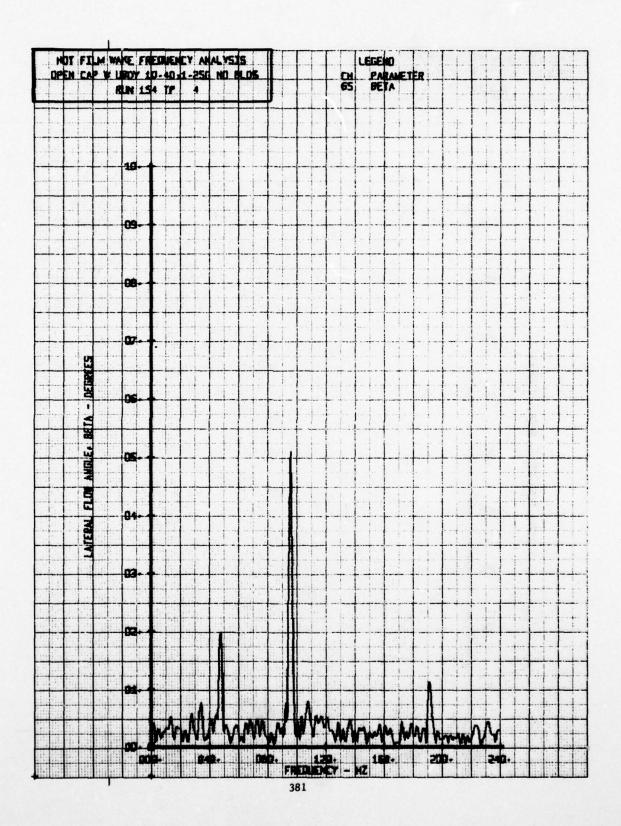




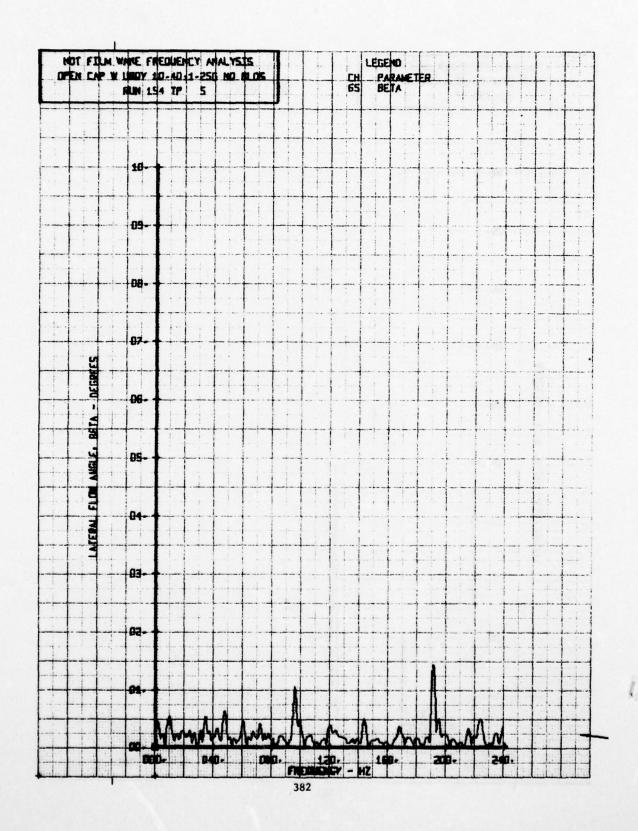


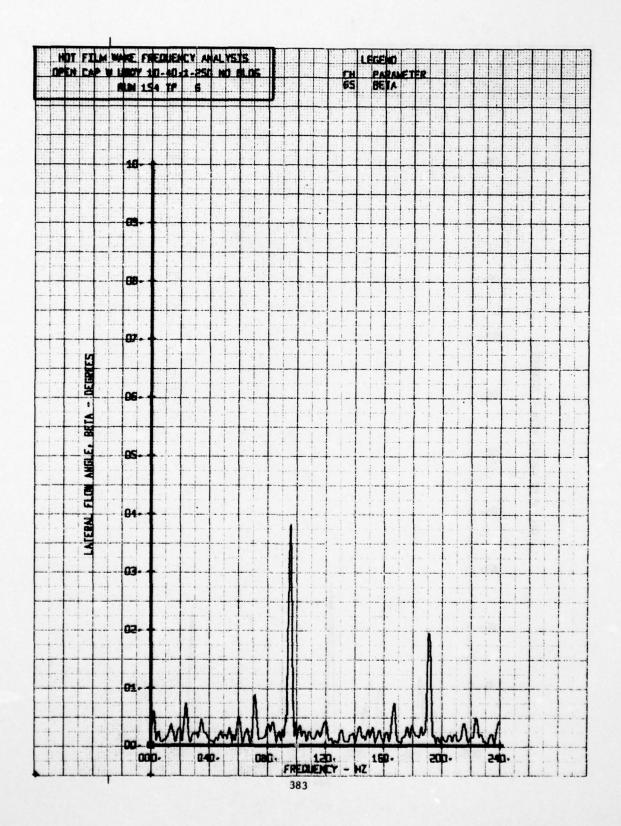
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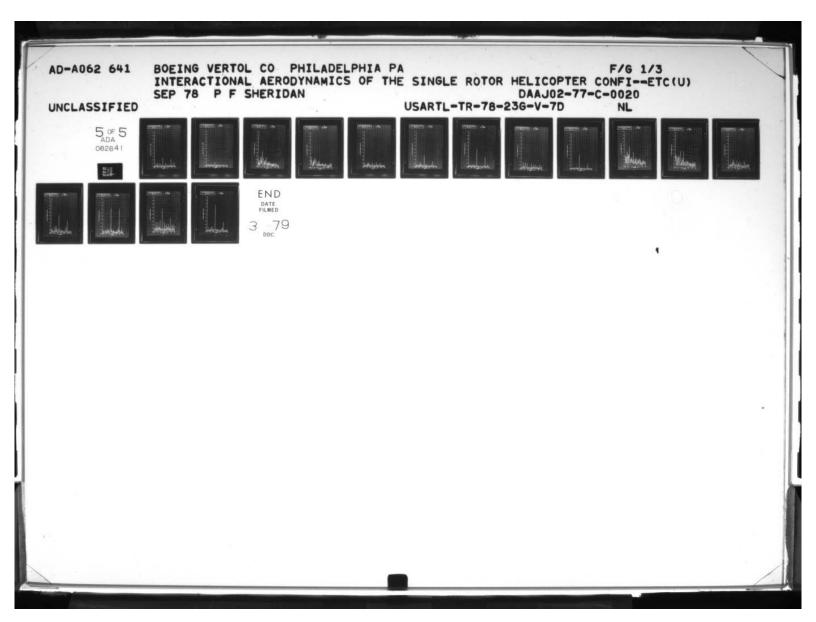


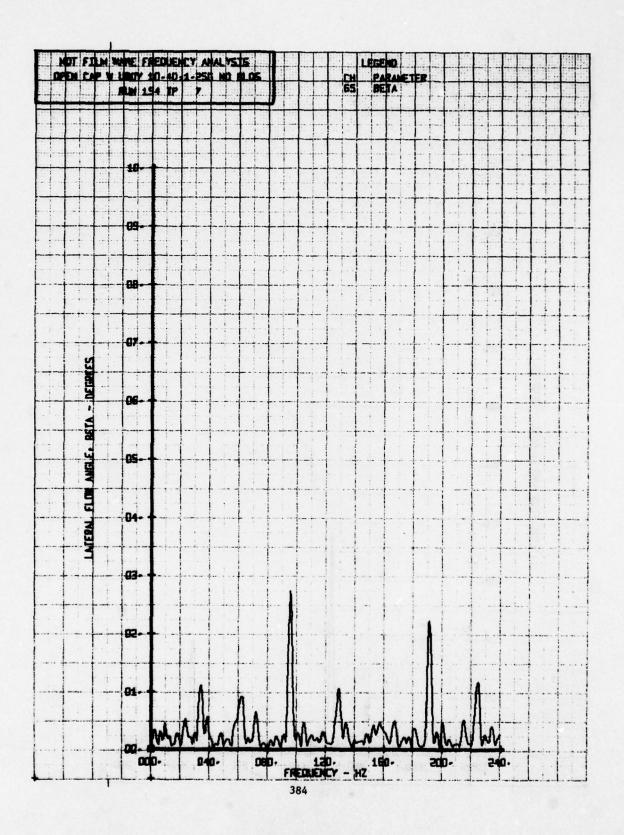


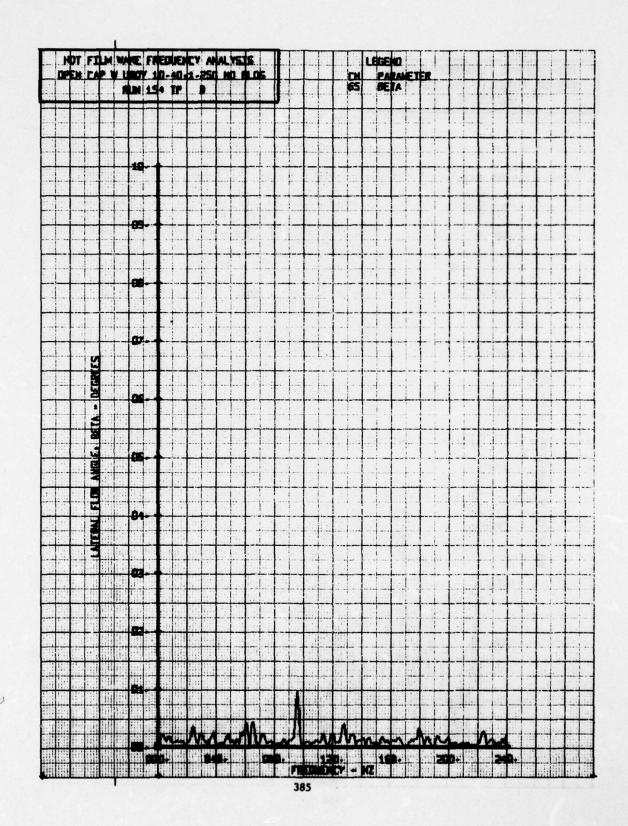
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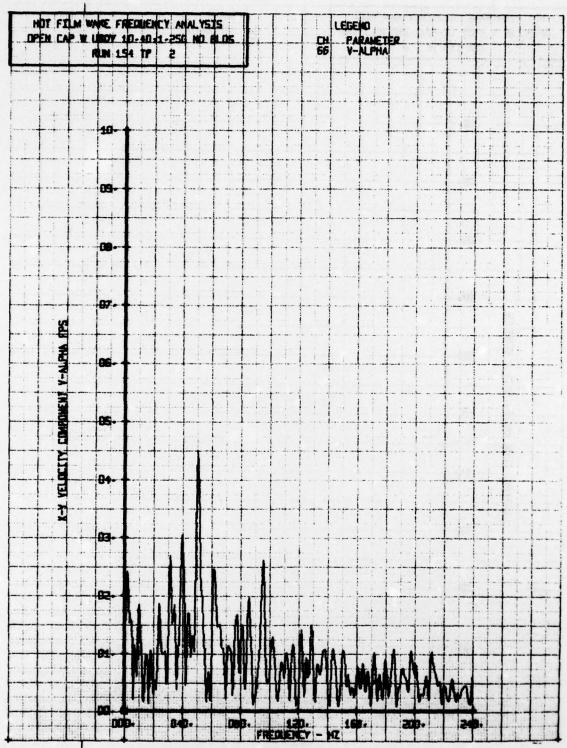




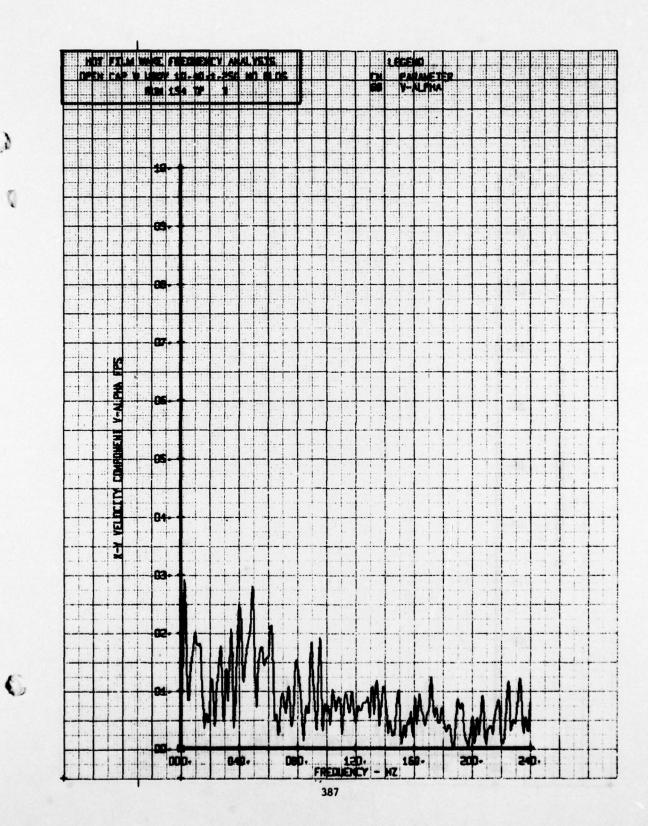


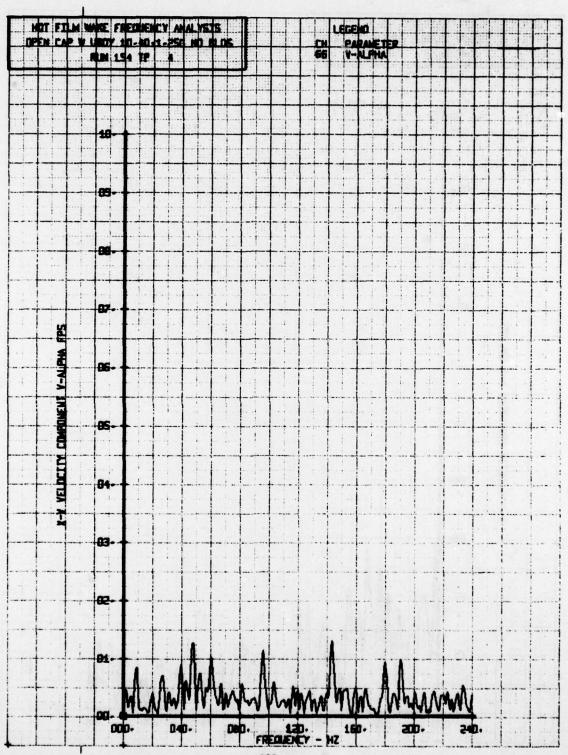


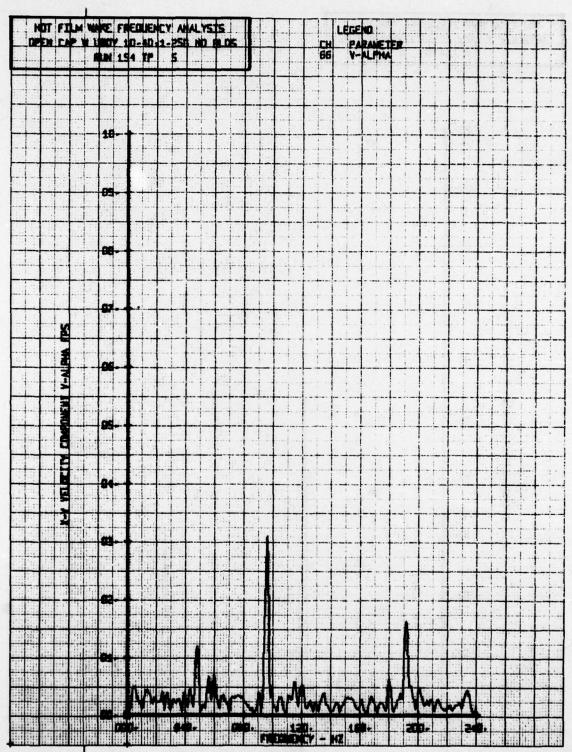
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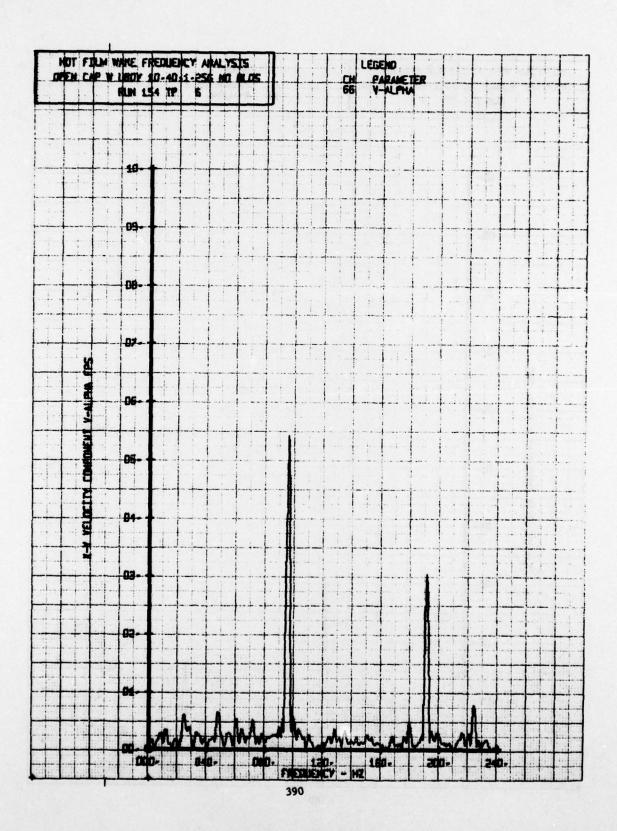


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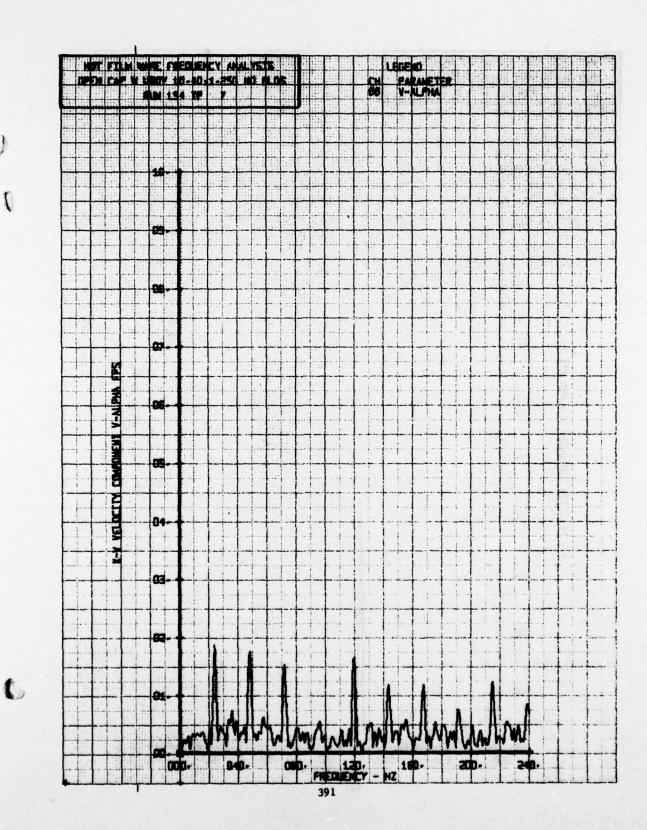


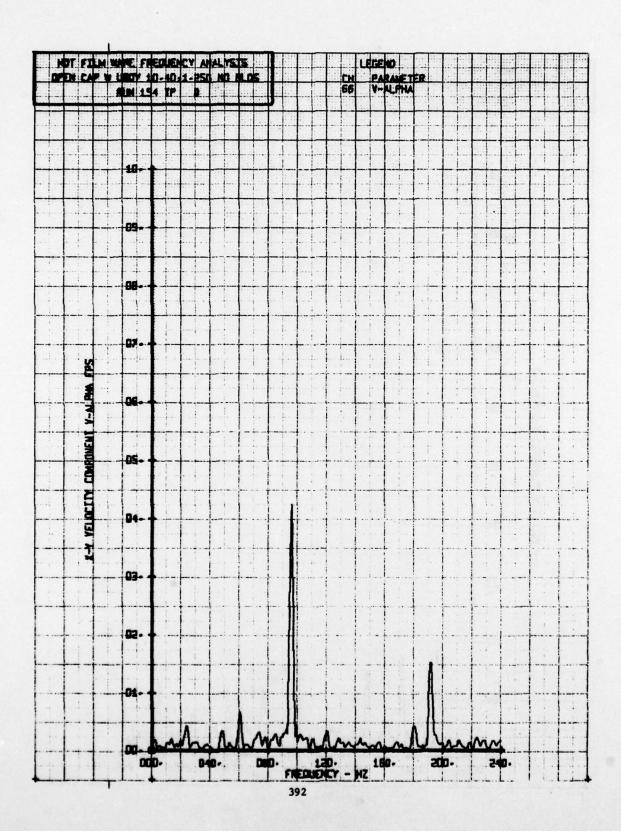


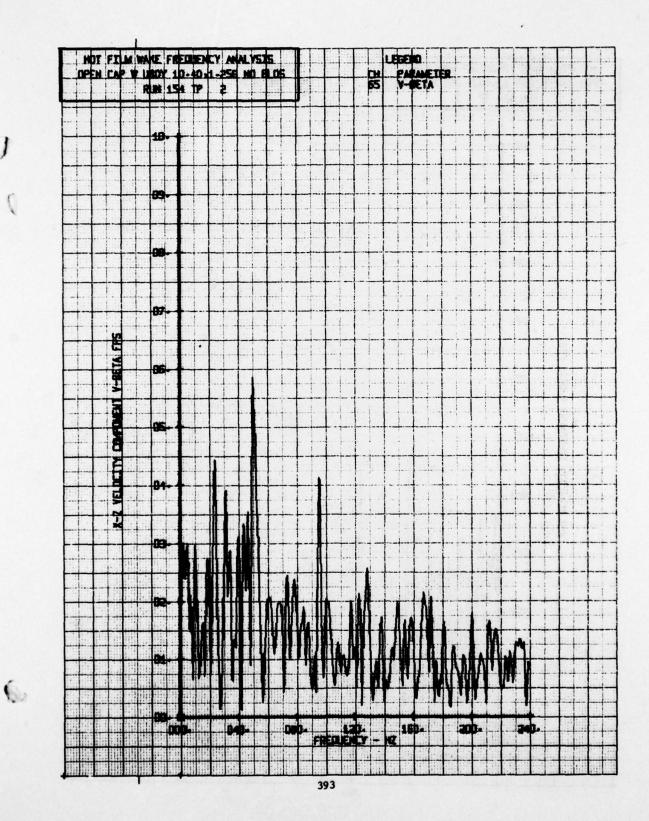




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